MODEL

293

Instruction Manual

UNIVERSAL IMPEDANC
MEASURING SYSTE

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BRIDGES AND ACCESSORIES

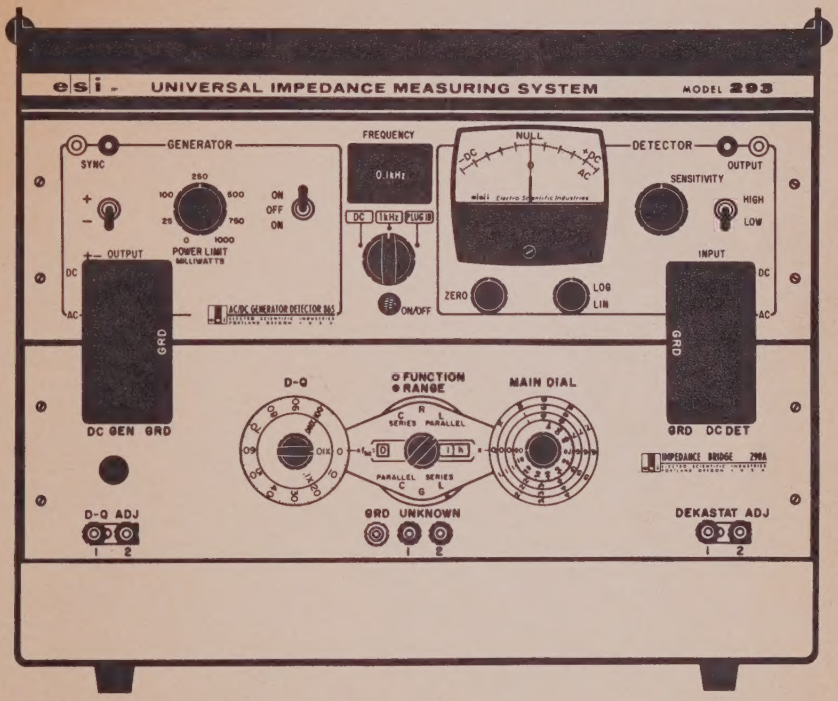
OCTOBER 1968

MODEL

293

Instruction Manual

UNIVERSAL IMPEDANCE MEASURING SYSTEM



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SERIAL NUMBER:_____

PART NUMBER: 19128

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865 AC/DC Generator-Detector Instruction Manual
290A Impedance Bridge Instruction Manual

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SECTION I

INTRODUCTION

1.1 DESCRIPTION

The ESI Model 293 Universal Impedance Measuring System consists of the ESI Model 865 AC/DC Generator-Detector and the ESI Model 290A Impedance Bridge.

The Model 865 AC-DC Generator-Detector furnishes either direct or alternating current to the bridge. It has a sensitive null detector for ac and dc balances. The Model 290A Impedance Bridge is used to measure resistance, conductance, inductance, and capacitance. It is also used to measure the dissipation factor and storage factor of inductors and capacitors. Resistance and conductance measurements are usually made with direct current because of the increased accuracy and the lack of stray reactance effects. Resistance and conductance measurements can be made using alternating current, but they may require external reactance compensation. Inductance and capacitance measurements are made in terms of a two-element circuit with the same impedance as the unknown.

An important feature of the Model 290A bridge is its ability to measure small three-terminal capacitors without zero-capacitance correction and without the use of a separate guard circuit or Wagner ground. The bridge internal shielding eliminates internal stray capacitance in parallel with the unknown.

Stray capacitance external to the bridge can be eliminated by using a shielded lead to the point of measurement.

1.2 SPECIFICATIONS

The following table lists the ranges and accuracies of the Model 290A Impedance Bridge for the six circuit configurations. Figures 1-1 and 1-2 summarize the accuracy graphically.

SELECTOR SWITCH SETTING	EQUIVALENT CIRCUIT	RANGES		ACCURACY △		
		MAGNITUDE	D or Q	L, R, C, G RANGE	MAGNITUDE	D or Q
R		0-1200 KILOHMS IN 7 RANGES;* 0.01 MILLIOHM PER DIAL DIV ON LOWEST R RANGE		HIGHEST	0.1% + 1 DIAL DIV	
				OTHER 5	0.05% + 1 DIAL DIV	
				LOWEST	0.1% + 1 DIAL DIV	
G		0-1200 MILLIMHOS IN 7 RANGES; 10 pmhos (100,000 MEGOHMS) PER DIAL DIVISION ON LOWEST G RANGE		HIGHEST	0.1% + 1 DIAL DIV	
				OTHER 5	0.05% + 1 DIAL DIV	
				LOWEST	0.1% + 1 DIAL DIV	
L Series		0-1200 HENRYS IN 7 RANGES; 0.01 μh PER DIAL DIV ON LOWEST L RANGE	Q=0 TO 10.5 x f_{kc} IN 3 RANGES 0.001 x f_{kc} PER DIAL DIV ON LOWEST Q RANGE	HIGHEST	0.2% + 1 DIAL DIV + 1.2% x f_{kc}/Q	0.012 f_{kc} $(1+Q^2)$ + 0.02Q
				OTHER 5	0.1% + 1 DIAL DIV + 0.7% x f_{kc}/Q	0.007 f_{kc} $(1+Q^2)$ + 0.02Q
				LOWEST	0.2% + 1 DIAL DIV + 0.7% x f_{kc}/Q	0.007 f_{kc} $(1+Q^2)$ + 0.02Q
L Parallel		0-1200 HENRYS IN 7 RANGES; 0.01 μh PER DIAL DIV ON LOWEST L RANGE	D=0 TO 10.5 x f_{kc} IN 3 RANGES 0.001 x f_{kc} PER DIAL DIV ON LOWEST D RANGE	HIGHEST	0.2% + 1 DIAL DIV + 1.2% x D x f_{kc}	0.012 f_{kc} $(1+D^2)$ + 0.02D
				OTHER 5	0.1% + 1 DIAL DIV + 0.7% x D x f_{kc}	0.007 f_{kc} $(1+D^2)$ + 0.02D
				LOWEST	0.2% + 1 DIAL DIV + 0.7% x D x f_{kc}	0.007 f_{kc} $(1+D^2)$ + 0.02D
C Series		0-1200 MICROFARADS IN 7 RANGES; 0.01 pf PER DIAL DIV ON LOWEST C RANGE	D=0 TO 10.5 x f_{kc} IN 3 RANGES 0.001 x f_{kc} PER DIAL DIV ON LOWEST D RANGE	HIGHEST	0.2% + 1 DIAL DIV + 0.5% x D x f_{kc}	0.005 f_{kc} $(1+D^2)$ + 0.02D
				OTHER 5	0.1% + 1 DIAL DIV + 0.5% x D x f_{kc}	0.005 f_{kc} $(1+D^2)$ + 0.02D
				LOWEST	0.2% + 1 DIAL DIV + 1.0% x D x f_{kc}	0.010 f_{kc} $(1+D^2)$ + 0.02D
C Parallel		0-1200 MICROFARADS IN 7 RANGES; 0.01 pf PER DIAL DIV ON LOWEST C RANGE	Q=0 TO 10.5 x f_{kc} IN 3 RANGES 0.001 x f_{kc} PER DIAL DIV ON LOWEST Q RANGE	HIGHEST	0.2% + 1 DIAL DIV + 0.5% x f_{kc}/Q	0.005 f_{kc} $(1+Q^2)$ + 0.02Q
				OTHER 5	0.1% + 1 DIAL DIV + 0.5% x f_{kc}/Q	0.005 f_{kc} $(1+Q^2)$ + 0.02Q
				LOWEST	0.2% + 1 DIAL DIV + 1.0% x f_{kc}/Q	0.010 f_{kc} $(1+Q^2)$ + 0.02Q

*Equivalent resistance measurements to 100,000 megohms are possible using the conductance ranges.

△ Accuracy specifications for inductors and capacitors apply for units with reasonably high Q (low D), at frequencies near 1 kc. The nominal frequency range is 100 cycles to 10 kc, with slight accuracy derating near the limits.

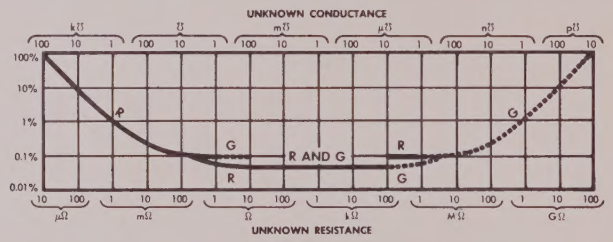

Figure 1-1. Resistance and Conductance Accuracy

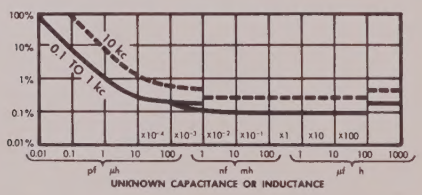

Figure 1-2. Capacitance and Inductance Accuracy

The sensitivity of the generator-detector combinations in the Model 293 Impedance Bridge is sufficient to make measurements with the accuracy listed through the following ranges:

Resistance: 0.5Ω to 1200 kΩ.

Conductance: 0 to 1200 mmhos (0.8Ω to 100,000MΩ).

Inductance: 1 μH to 1200 H for inductors with low loss.

Capacitance: 0 to 500 μF for capacitors with low loss.

SECTION II

OPERATION

2.1 INTERCONNECTION

Basic interconnection of the instruments is shown in Figure 2-1. The instruments may be connected differently for purposes other than normal measurement of resistance, conductance, capacitance and inductance. The different uses of the system are described in the manuals for the individual instruments, especially the manual for the Model 290 Impedance Bridge.

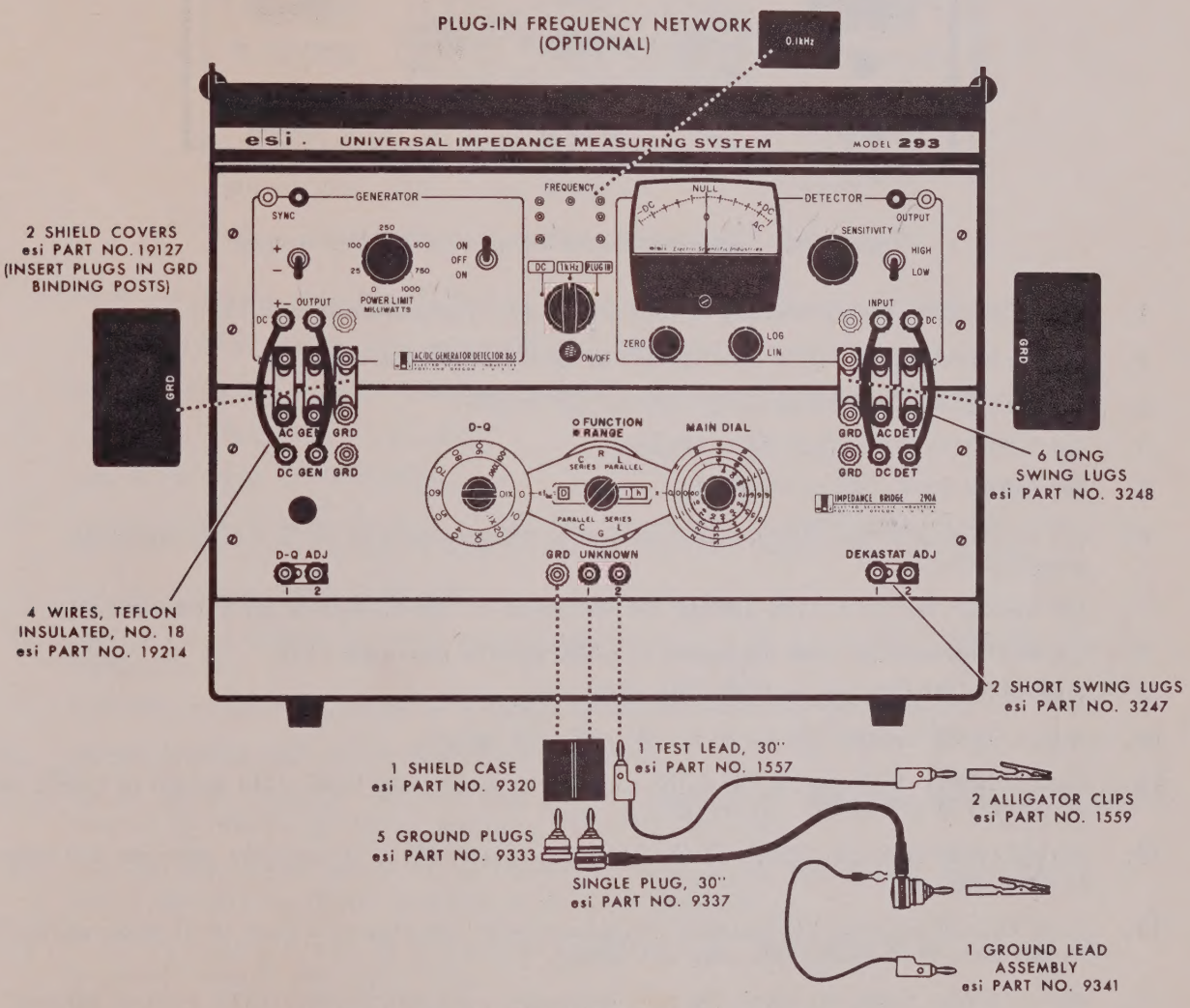

Figure 2-1. Model 293 Interconnection

2.2 DC RESISTANCE AND CONDUCTANCE MEASUREMENT

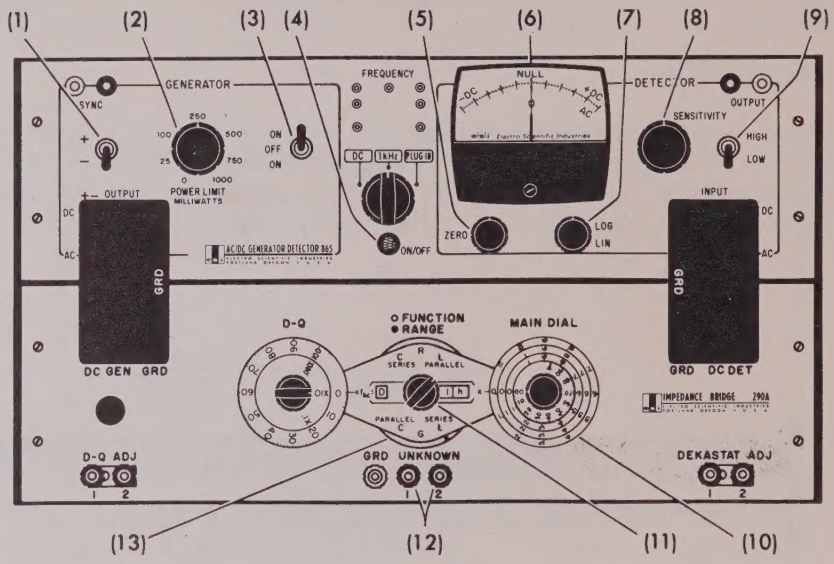

Figure 2-2. Resistance and Conductance Measurement

1. Press ON/OFF pushbutton (4) to turn on power. Pushbutton should light.
2. Set GENERATOR ON/OFF switch (3) to OFF (center position).
3. Set GENERATOR POWER LIMIT control (2) to 250.
4. Set SENSITIVITY switch (9) to HIGH.
5. Set MAIN DIAL (10) to 11.0000.
6. Set FUNCTION dial (13) to R for resistance measurement or to G for conductance measurement.
7. Set RANGE switch (11) to 100kΩ for resistance or 100 milliohms for conductance.
8. Connect resistance to be measured to UNKNOWN terminals (12).
9. Turn SENSITIVITY control (8) fully clockwise.
10. Adjust ZERO control (5) for meter (6) null indication.
11. Turn SENSITIVITY control (8) fully counterclockwise, set LOG-LIN switch to LOG, and set SENSITIVITY switch (9) to LOW.
12. Set GENERATOR ON/OFF switch (1) to + . Meter (6) will probably indicate full scale to the right.
13. Turn RANGE switch (11) counterclockwise slowly one step at a time until meter (6) deflects to the left, then switch one step clockwise.
14. Adjust MAIN DIAL for meter (6) null indication, turning SENSITIVITY control (8) and SENSITIVITY switch (9) to increase sensitivity as necessary.
15. Turn GENERATOR POWER LIMIT control (2) clockwise for more power if necessary.
16. Read resistance or conductance on MAIN DIAL (10) and RANGE dial (11).

2.3 AC CAPACITANCE AND INDUCTANCE MEASUREMENT

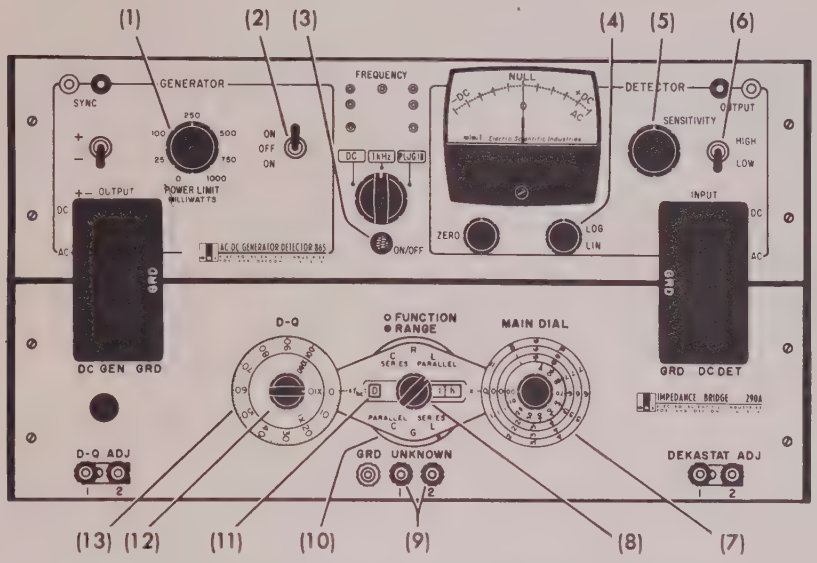

Figure 2-3. Capacitance and Inductance Measurement

1. Press ON/OFF pushbutton (3) to turn on power. Pushbutton should light.
2. Set GENERATOR ON-OFF switch (2) to OFF (center position).
3. Set GENERATOR POWER LIMIT control (1) to 250.
4. Set LOG-LIN switch (4) to LOG.
5. Set MAIN DIAL (7) to 3.0000.
6. Set FUNCTION dial (10) to C SERIES for capacitors or L PARALLEL for inductors unless the unknown is very lossy, in which case set dial to C PARALLEL or L SERIES.
7. Set D-Q range dial (12) to .1X.
8. Set D-Q dial (13) to 0 if indication in window (11) is D, or to 100 if indication in window is Q.
9. Connect unknown capacitor or inductor to UNKNOWN terminals (9).
10. Adjust RANGE dial (8) for lowest meter reading.
11. Adjust MAIN DIAL (7) and D-Q dial (13) for lowest meter reading. Adjust SENSITIVITY control (5) and switch (6) as necessary for more sensitivity.
12. If a null can not be obtained, turn FUNCTION dial (10) from SERIES to PARALLEL or from PARALLEL to SERIES and repeat steps 7 through 10.
13. If MAIN DIAL (7) reading is less than 1.2000 at null, turn RANGE dial (8) one step counterclockwise and repeat step 9.
14. If D-Q dial (13) reading is less than 10 at null and D-Q range dial (12) setting is not .001X, turn D-Q range dial one step clockwise and repeat step 9.

SECTION III

LIST OF ACCESSORIES

The following list of items are in the interconnection kit (ESI Part No. 19129) for the Model 293 Universal Impedance Measuring System. All items listed are manufactured and/or supplied by Electro Scientific Industries, Inc., 13900 N.W. Science Park Drive, Portland, Oregon and may be ordered from the factory.

The Federal Supply Code for Manufacturers (FSC) for Electro Scientific Industries is 11837.

When ordering parts, please include the following information:

Name and model number of the system (Model 293 Universal Impedance Measuring System)

ESI part number

Description of part

DESCRIPTION	PART NO.	QTY USED
Alligator Clips	1559	2
Cable Assembly, Single Plug, 30 inch	9337	1
Ground Lead Assembly	9341	1
Ground Plug	9333	1
Instruction Manual	19128	1
Shield Case, 2-Hole	9320	1
Shield Covers	19127	2
Swing Lug, Long	3248	6
Swing Lug, Short	3247	2
Test Lead, 30 inch	1557	1
Wire, Teflon Insulated, No. 18	19214	4

May 1969

ESI® INSTRUCTION MANUAL CHANGES

Model 293 Universal Impedance Measuring System

Instruction Manual dated October 1968

1. Page 2-2:

   Change step 12 to read as follows:

   12. Set GENERATOR OUTPUT switch (1) to + and set ON/OFF switch (3) to either ON position. Meter (6) will probably indicate full scale to the right.

2. Page 2-3:

   Change step 10 to read as follows:

   10. Set GENERATOR ON/OFF switch (2) to either ON position and adjust RANGE dial (8) for lowest meter reading.

Part No. 19128-2

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KELVIN KLAMPS® Four-Terminal Clamps
KELVIN KLIPS® Four-Terminal Clips
PORTAMETRIC® Portable Measuring Instrument
PVB® Potentiometric Voltmeter Bridge

SECTION I

INTRODUCTION

1.1 DESCRIPTION

ESI Model 865 AC/DC Generator-Detector is a combined ac and dc signal source and null detector for impedance bridges, resistance bridges, and for calibration of voltage dividers. The generator is power-limited to a maximum of 1 watt in order to protect bridge circuits, unknown components, and the detector from overloads. The detector has a zero-centered meter for both ac and dc; both polarities are used for dc and ac is indicated on the right half of the meter.

Simplified schematic diagrams are shown in Figures 1-1 and 1-2.

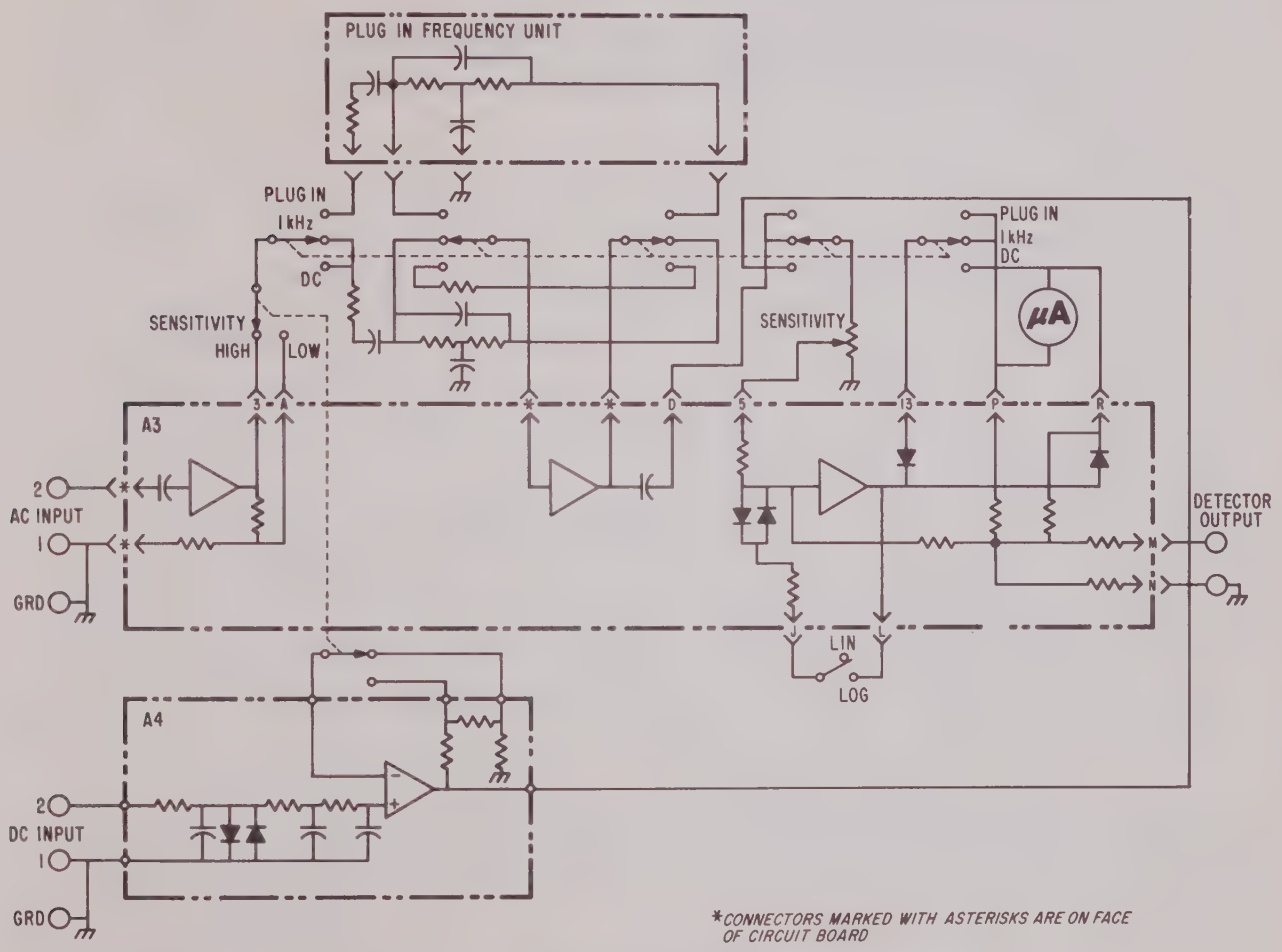


Figure 1-1. Detector Simplified Schematic Diagram

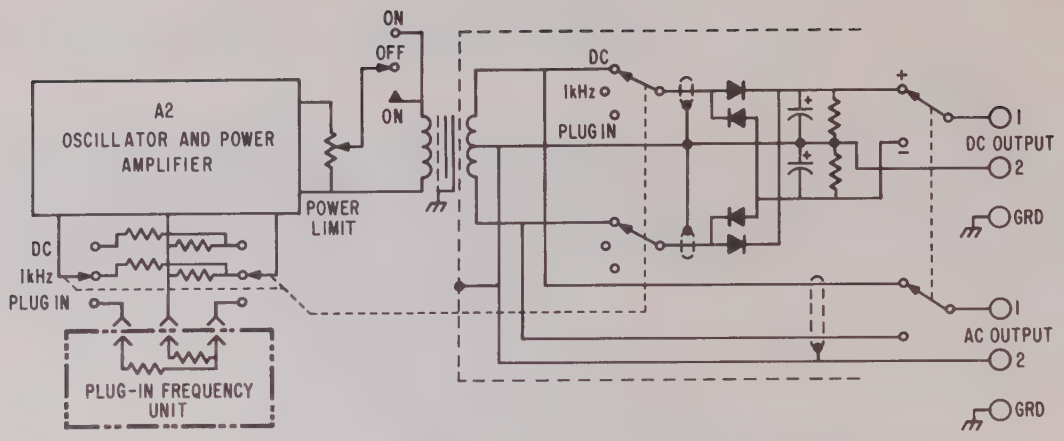


Figure 1-2. Generator Simplified Schematic Diagram

1.2 SPECIFICATIONS

1.2.1 Generator

Frequency: DC, 1 kHz, or other frequency established by plug-in frequency network.

Frequency Accuracy: ±1%.

Output Voltage: 0 to 6 V, continuously variable.

Output Power: Limited to 1 W maximum.

Output Isolation: $10^{10}\Omega$ to case minimum; 150 pF maximum between terminal 2 and case, 10 pF maximum between terminal 1 and case.

Output Polarity: Switch reverses dc polarity or ac phase.

Synchronizing: SYNC connector provides phase-lock input or output signal.

1.2.2 Detector

Frequency: Tuned to generator frequency.

Sensitivity: Continuously variable in two ranges; 5 μV minimum detectable signal.

Input Impedance

DC: Greater than 10 MΩ.

AC: Greater than 10 MΩ shunted by less than 40 pF.

Null Indication: Zero-centered meter, polarity indicated on dc, ac magnitude indicated on right-hand side of meter.

Response: Logarithmic or linear response selected with LOG/LIN switch.

Output: Voltage of magnitude proportional to meter indication at OUTPUT terminal.

Output Level: Approximately 0.15 V for full scale indication; 10 kΩ output resistance.

1.2.3 Plug-In Frequency Networks

Networks are available in the following frequencies: 60, 100, 120, and 400 Hz, 1 and 10 kHz. Other frequencies between 50 Hz and 10 kHz are available on special order.

1.2.4 Miscellaneous

Power Requirement: 115 V, 50 to 400 Hz. (230 V models available)

Dimensions: Width 19.0 in. (48.25 cm), height 5.25 in. (13.33 cm), depth 8.0 in. (20.32 cm).

Weight: 10 lb (4.53 kg).

SECTION II

OPERATION

2.1 TERMINALS AND CONTROLS

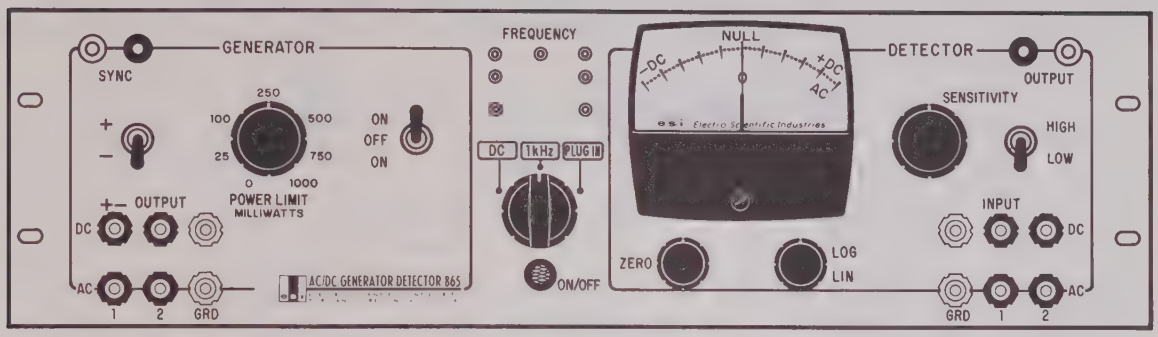


Figure 2-1. Front Panel

ON/OFF pushbutton controls line power to generator and detector. The pushbutton lights red when the power is on.

FREQUENCY switch selects the frequency-determining network for both the generator and detector and connects the inputs and outputs for ac and dc operation. The switch can select dc, 1 kilohertz, or the frequency determined by the plug-in network.

POLARITY switch selects the polarity of dc voltage or selects the phase of the ac voltage. The polarity marked (+ or -) corresponds to the polarity at the DC OUTPUT ± terminal.

POWER LIMIT control adjusts the maximum output power from 0 to 1000 milliwatts. This corresponds to a voltage from 0 to approximately 6 volts. The approximate power limit is indicated by the control dial.

GENERATOR ON-OFF switch applies power to the OUTPUT terminals. There are two ON positions; the lower one is a momentary contact which will return the switch to OFF whe it is released, the upper position holds the power on.

OUTPUT binding posts connect output ac and dc to the measurement circuit. The appropriate set of binding posts is selected by the FREQUENCY switch.

SYNC jacks can be used either as an input for phase-locking or as an output for synchronizing an oscilloscope, for operating a counter to determine frequency accurately, or for other equipment.

ZERO control adjusts the dc detector zero.

LOG/LIN control selects the type of detector response, logarithmic or linear.

SENSITIVITY controls consist of a switch that selects the high or low sensitivity range and a rheostat that adjusts the sensitivity as desired.

INPUT binding posts connect ac and dc from the measurement circuit to the detector. Each set of binding posts is connected to the input of an amplifier circuit. The outputs of the amplifiers are selected by the FREQUENCY switch.

DETECTOR OUTPUT jacks connect to the output of the detector final amplifier. The output voltage is ac or dc as selected by the FREQUENCY switch and has a magnitude proportional to the indication of the meter.

2.2 BASIC OPERATING PROCEDURE

The Model 865 is normally used to apply a dc voltage to a resistive measurement circuit or an ac voltage to a reactive circuit and to adjust the circuit for null, observing the output with the detector.

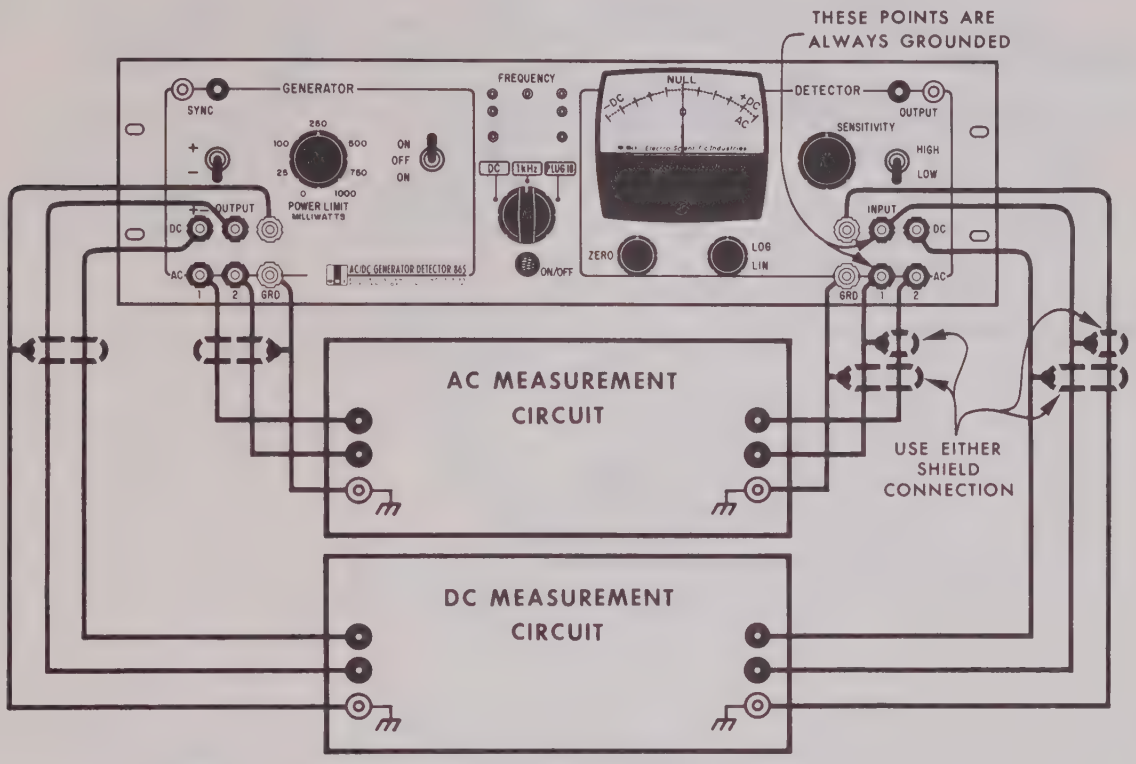


Figure 2-2. Basic Operating Procedure

1. Be sure that the power cord is plugged into the line and press ON/OFF push-button to turn on instrument.	Pushbutton should light when power is on.
2. Connect measurement circuit to GENERATOR OUTPUT and DETECTOR INPUT binding posts as illustrated in Figure 2-2.	DETECTOR INPUT AC and DC binding posts 1 are grounded.
3. Turn SENSITIVITY control fully clockwise for maximum gain, set switch to HIGH, set FREQUENCY switch to DC, turn generator to OFF and adjust ZERO control for meter zero.	Always adjust detector zero with detector input connected to measurement circuit. This step is not necessary for ac measurements. There will be some dc zero drift during initial warmup period.
4. Turn SENSITIVITY control fully counter-clockwise for minimum gain, set switch to LOW, and set FREQUENCY switch to appropriate setting.	Be sure that a plug-in frequency is installed before setting FREQUENCY control to PLUG-IN.

5. Set POWER LIMIT control to a value that will not cause component value changes due to heating or voltage coefficient effects.	Experience and experiment will establish the proper setting. If there is a chance of damaging some component, use a low setting and increase it only when it is apparent that there is not engugh power.
6. Turn on generator with GENERATOR OFF ON switch.	For dc measurements, the indicated polarity is the polarity at the ± binding post.
7. Set LOG/LIN switch as desired.	The LOG setting is recommended for measurements that may be far from null, the LIN setting is recommended for adjustments that result in small changes of detector voltage. When in doubt, try the LOG setting.
8. Adjust the measurement circuit for null.	Turn SENSITIVITY control clockwise and set switch to HIGH for more sensitivity.

2.3 BRIDGE CONNECTIONS

Figures 2-3 and 2-4 illustrate typical connections to resistance and impedance bridges.

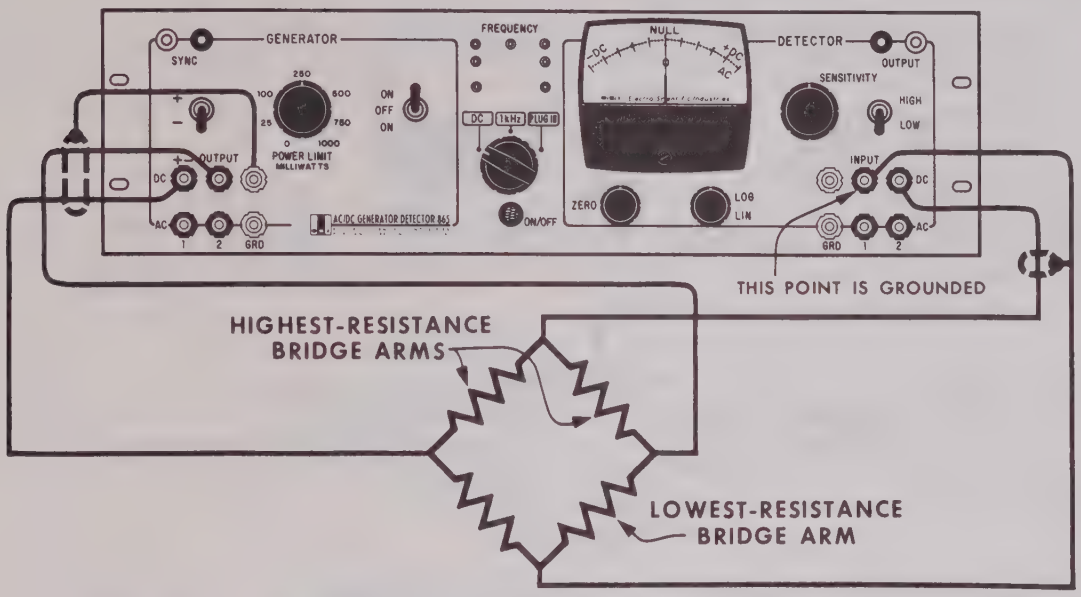


Figure 2-3. Resistance Bridge Connection

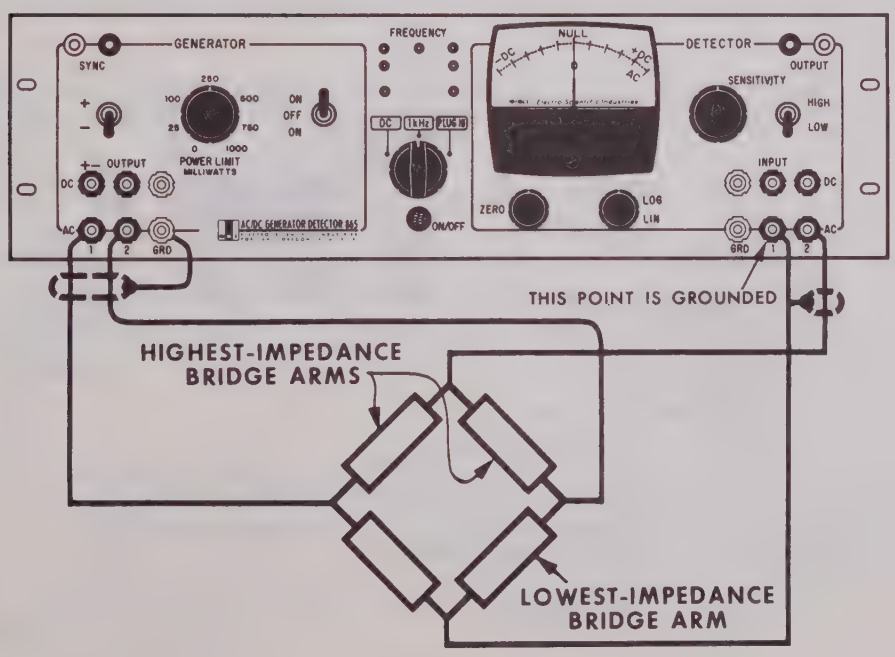


Figure 2-4. Impedance Bridge Connection

2.4 VOLTAGE DIVIDER CALIBRATION

Figure 2-5 illustrates connections to resistive dividers. Note the end compensation. ESI Model LC 875B can be used for this purpose.

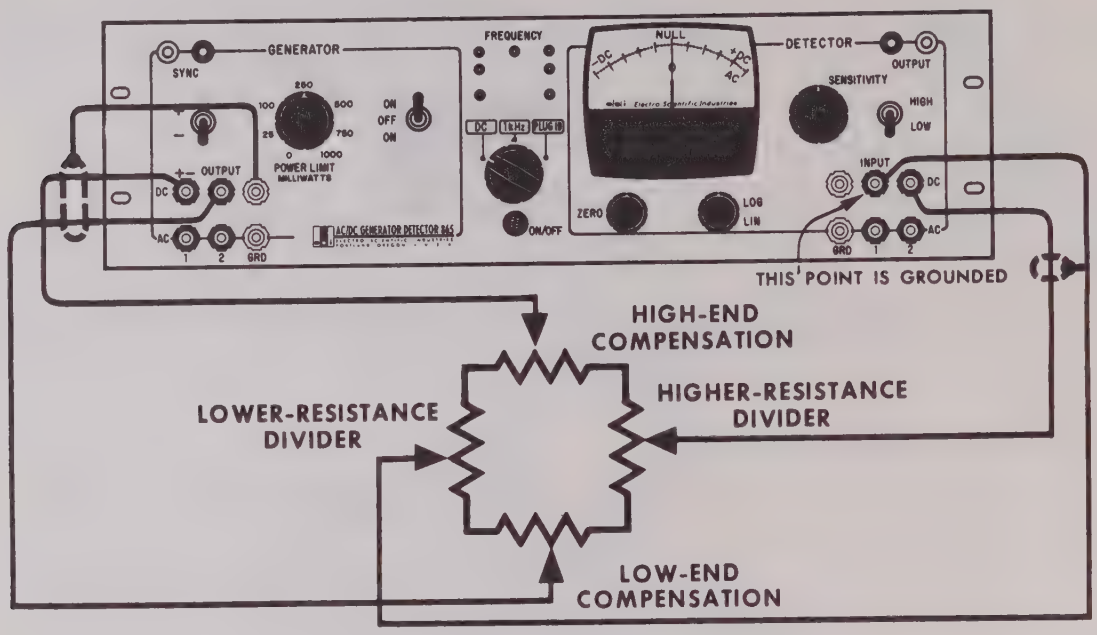


Figure 2-5. Resistive Divider Connection

Figure 2-6 illustrates connections to inductive voltage dividers. This circuit includes phase compensation. The resistor-capacitor combination is included in ESI Model PC 874 which can be used for this purpose.

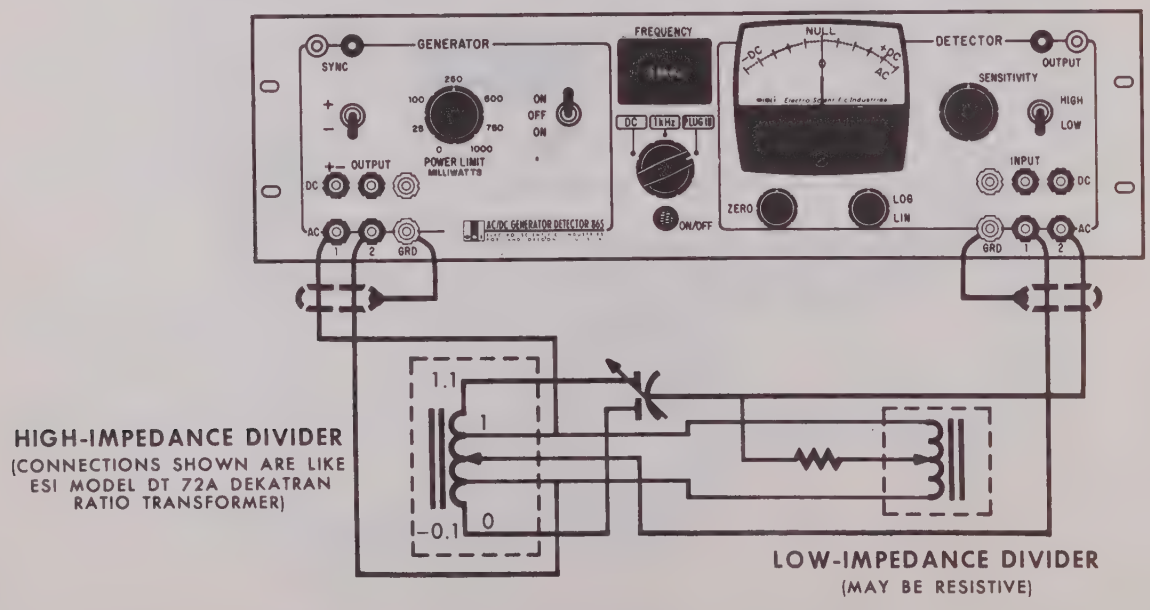


Figure 2-6. Inductive Voltage Divider Connection

2.5 AUXILIARY OPERATION

2.5.1 Generator Synchronization

The generator SYNCH jacks can be used either as input or an output. An input signal (preferably a sine wave) can be applied to lock the generator to an external source in phase and frequency. The frequency range for control is ±5 percent per volt (rms) with a maximum of 10 volts. If a non-sine waveform is used, the output waveform of the generator will be slightly distorted.

The output of the SYNCH terminals is a constant amplitude (2-volt rms) signal with a source impedance of approximately 5 kilohms. This signal can be used to drive a counter, synchronise an oscilloscope, or perform other similar service. The output may be short-circuited without affecting the operation of the generator.

2.5.2 Detector Output

The detector OUTPUT jacks connect to the final output amplifier of the detector. The output voltage at these jacks is proportional to the meter deflection. When the FREQUENCY switch is set to DC, the output is a dc voltage of the polarity indicated by the meter and approximately 0.15 volts at full scale. When the FREQUENCY switch is set to either ac position, the output is ac with an amplitude proportional to the meter indication. This output is highly distorted if the LOG-LIN switch is set to LOG.

The impedance of the output voltage (either ac or dc) is approximately 10 kilohms. The output may be short-circuited with very little effect on the operation of the detector.

SECTION III

MAINTENANCE

3.1 PREVENTIVE MAINTENANCE

The following procedures should be performed periodically (approximately once a year) to insure maximum accuracy and reliability from the Model 865 Generator-Detector.

If the need for major repairs is apparent, it is recommended that the unit be sent to the factory for service. The service department will be glad to furnish the necessary information for repairs as well as any replacement parts. However, unauthorized repairs will invalidate the instrument warranty.

3.1.1 Visual Inspection

Inspect the unit for dial orientation and damage to binding posts and binding post caps. Also check for dirt around the binding post insulators. Then remove the case as described in Paragraph 3.1.2 and inspect the unit for possible internal defects. These defects include such things as loose or broken connections, damaged or dirty switch contacts, and heat-damaged resistors.

3.1.2 Removing the Case

Prepare a soft, clean place to set the instrument. Be sure that no projections or pointed objects will be underneath the panel. See that there are no metal filings in the area.

Place the unit face down on the prepared surface. Remove the screws on the back of the instrument and carefully slide the case off.

3.1.3 Cleaning and Lubrication

Clean the front panel with a soft, dry, lint-free cloth, being particularly careful to remove all dirt from around the binding post insulators. The only internal components that require cleaning and lubrication are the switches.

The switches are carefully lubricated at the time of manufacture and are protected from contamination by the instrument case. They should rarely, if ever, require maintenance. It is recommended that they be cleaned or lubricated only if it is determined that they are not making good electrical contact. If the switch decks are in need of cleaning or lubrication, proceed as follows:

a) Apply solvent (Freon TE solvent or equivalent) to the contact surfaces with a small brush or pipe cleaner.

b) Wipe surfaces with clean, dry brush or dry with low-pressure air.

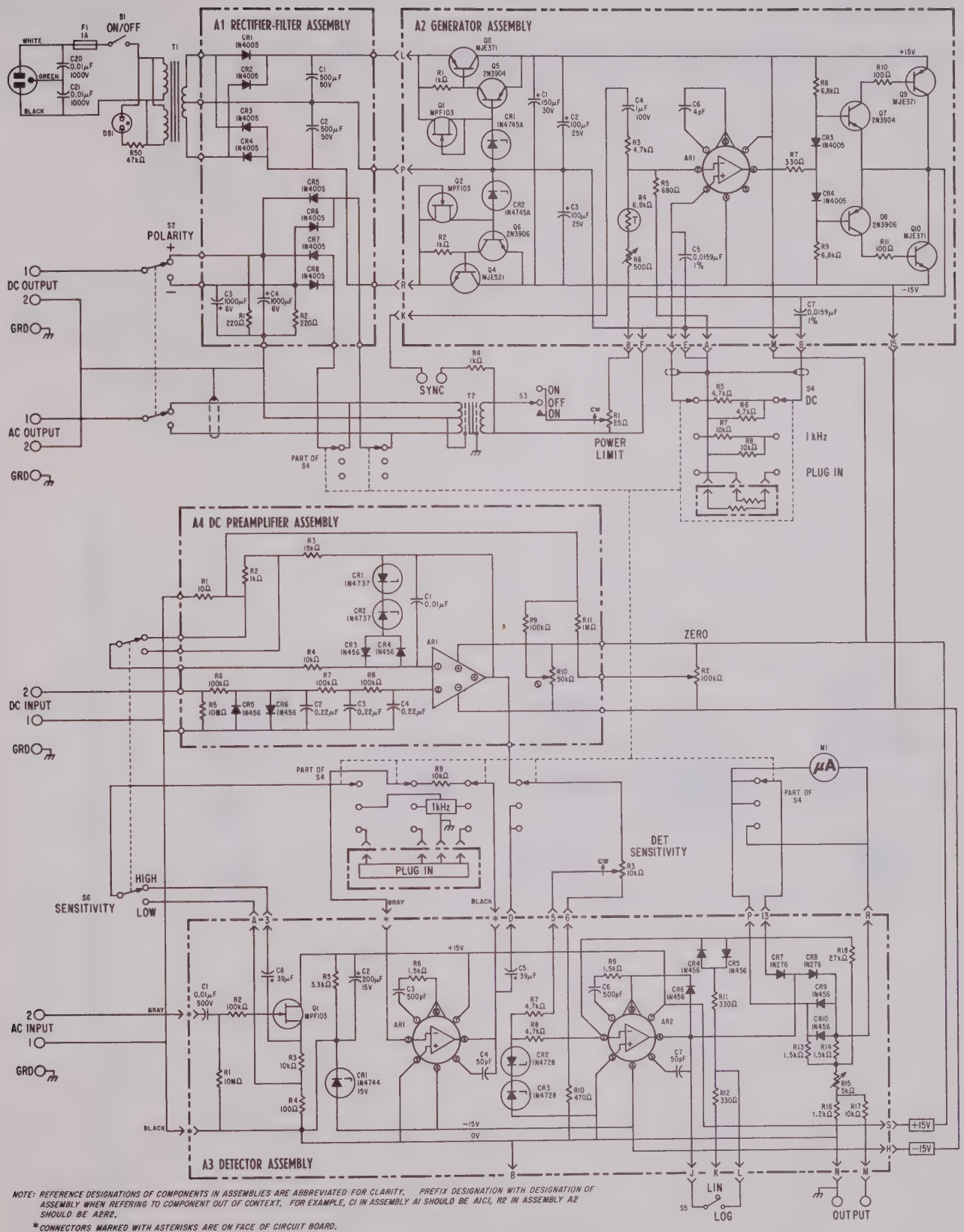
c) Apply a thin coating of lubricant (Oak #2008 or equivalent) to the contact surfaces with a hypodermic needle.

d) Apply two drops of the same oil to each of the switch bearings and detent mechanisms.

e) Remove excess oil with a clean, dry cloth and remove all traces of lint with a soft brush.

3.1.4 Replace the Case

Be sure that the interior of the case is completely clear of all foreign material. Slip the case over the unit and replace the screws.



NOTE: REFERENCE DESIGNATIONS OF COMPONENTS IN ASSEMBLIES ARE ABBREVIATED FOR CLARITY. PREFIX DESIGNATION WITH DESIGNATION OF ASSEMBLY WHEN REFERING TO COMPONENT OUT OF CONTEXT. FOR EXAMPLE, C1 IN ASSEMBLY A1 SHOULD BE A1C1, R2 IN ASSEMBLY A2 SHOULD BE A2R2.

*CONNECTORS MARKED WITH ASTERISKS ARE ON FACE OF CIRCUIT BOARD.

Figure 3-1. Model 865 Schematic Diagram

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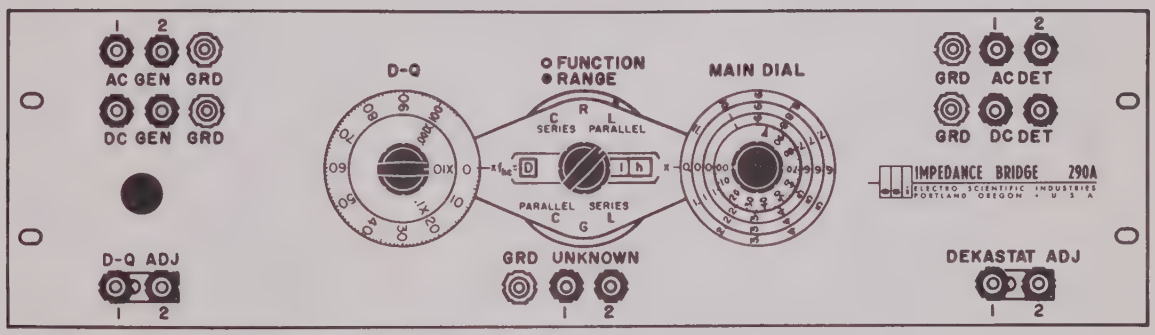
BRIDGES AND ACCESSORIES

JUNE 1966
REPLACES OCTOBER 1963

MODEL
290A

Instruction Manual

UNIVERSAL IMPEDANCE MEASURING SYSTEM



SERIAL NUMBER: _____

PART NUMBER: 3207

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6. CONVENIENT AUDIO FREQUENCY UNITS

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1. INTRODUCTION

The ESI Model 290A Impedance Bridge combines a resistance, conductance, inductance, and capacitance bridge. Dissipation factor (D) and storage factor (Q) of inductors and capacitors are measured as part of the measurement of the primary characteristic.

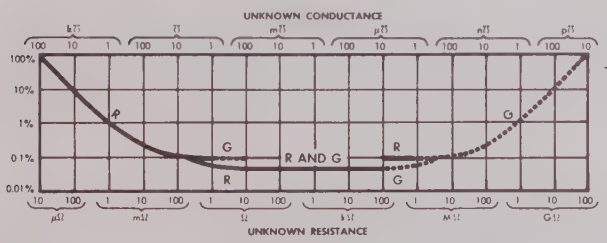
1.1 Specifications

The specified range and accuracy of the instrument are shown in the following table and graphs.

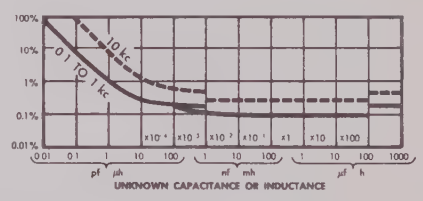
SELECTOR SWITCH SETTING	EQUIVALENT CIRCUIT	RANGES		ACCURACY △		
		MAGNITUDE	D or Q	L, R, C, G RANGE	MAGNITUDE	D or Q
R	R	0-1200 KILOHMS IN 7 RANGES;* 0.01 MILLIOHM PER DIAL DIV ON LOWEST R RANGE		HIGHEST	0.1% + 1 DIAL DIV	
				OTHER 5	0.05% + 1 DIAL DIV	
				LOWEST	0.1% + 1 DIAL DIV	
G	G	0-1200 MILLIMHOS IN 7 RANGES; 10 pmhos (100,000 MEGOHMS) PER DIAL DIVISION ON LOWEST G RANGE		HIGHEST	0.1% + 1 DIAL DIV	
				OTHER 5	0.05% + 1 DIAL DIV	
				LOWEST	0.1% + 1 DIAL DIV	
L Series	L_s Q	0-1200 HENRYS IN 7 RANGES; 0.01μh PER DIAL DIV ON LOWEST L RANGE	Q=0 TO 10.5×f_{kc} IN 3 RANGES 0.001×f_{kc} PER DIAL DIV ON LOWEST Q RANGE	HIGHEST	0.2% + 1 DIAL DIV + 1.2% × f_{kc}/Q	0.012f_{kc} $(1+Q^2)$ + 0.02Q
				OTHER 5	0.1% + 1 DIAL DIV + 0.7% × f_{kc}/Q	0.007f_{kc} $(1+Q^2)$ + 0.02Q
				LOWEST	0.2% + 1 DIAL DIV + 0.7% × f_{kc}/Q	0.007f_{kc} $(1+Q^2)$ + 0.02Q
L Parallel	L_p D	0-1200 HENRYS IN 7 RANGES; 0.01μh PER DIAL DIV ON LOWEST L RANGE	D=0 TO 10.5×f_{kc} IN 3 RANGES 0.001×f_{kc} PER DIAL DIV ON LOWEST D RANGE	HIGHEST	0.2% + 1 DIAL DIV + 1.2% × D×f_{kc}	0.012f_{kc} $(1+D^2)$ + 0.02D
				OTHER 5	0.1% + 1 DIAL DIV + 0.7% × D×f_{kc}	0.007f_{kc} $(1+D^2)$ + 0.02D
				LOWEST	0.2% + 1 DIAL DIV + 0.7% × D×f_{kc}	0.007f_{kc} $(1+D^2)$ + 0.02D
C Series	C_s D	0-1200 MICROFARADS IN 7 RANGES; 0.01pf PER DIAL DIV ON LOWEST C RANGE	D=0 TO 10.5×f_{kc} IN 3 RANGES 0.001×f_{kc} PER DIAL DIV ON LOWEST D RANGE	HIGHEST	0.2% + 1 DIAL DIV + 0.5% × D×f_{kc}	0.005f_{kc} $(1+D^2)$ + 0.02D
				OTHER 5	0.1% + 1 DIAL DIV + 0.5% × D×f_{kc}	0.005f_{kc} $(1+D^2)$ + 0.02D
				LOWEST	0.2% + 1 DIAL DIV + 1.0% × D×f_{kc}	0.010f_{kc} $(1+D^2)$ + 0.02D
C Parallel	C_p Q	0-1200 MICROFARADS IN 7 RANGES; 0.01pf PER DIAL DIV ON LOWEST C RANGE	Q=0 TO 10.5×f_{kc} IN 3 RANGES 0.001×f_{kc} PER DIAL DIV ON LOWEST Q RANGE	HIGHEST	0.2% + 1 DIAL DIV + 0.5% × f_{kc}/Q	0.005f_{kc} $(1+Q^2)$ + 0.02Q
				OTHER 5	0.1% + 1 DIAL DIV + 0.5% × f_{kc}/Q	0.005f_{kc} $(1+Q^2)$ + 0.02Q
				LOWEST	0.2% + 1 DIAL DIV + 1.0% × f_{kc}/Q	0.010f_{kc} $(1+Q^2)$ + 0.02Q

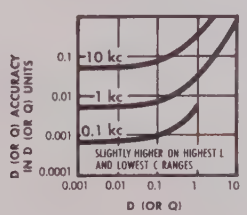
*Equivalent resistance measurements to 100,000 megohms are possible using the conductance ranges.

△ Accuracy specifications for inductors and capacitors apply for units with reasonably high Q (low D), at frequencies near 1 kc. The nominal frequency range is 100 cycles to 10 kc, with slight accuracy derating near the limits.

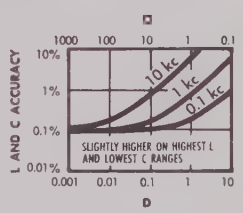


These curves show the specified accuracy for measurements of resistors and low loss inductors and capacitors.





The accuracy of inductance and capacitance measurements is influenced by the D or Q value. Graphs show the accuracy to be expected at various values of D or Q.



1.2 Accessories Required

1.2.1 For DC Measurements:

The ESI Models 800, 803, and 840 DC Generator-Detector or the 810 DC Detector and the 820 DC Generator are recommended for use with the Model 290A Bridge. If other dc generator and detector units are used, they should meet the following specifications:

DC Generator

Isolation: Resistance to ground must exceed 10 terohms, (10^{13} ohms).

Maximum Voltage: 400 volts open circuit.

Output Power: Limited to 1 watt or less

For example:

1.5 volts in series with 0.5 ohms or more
10 volts in series with 25 ohms or more
300 volts in series with 25 kilohms or more

1.2.2 DC Detector

Either a galvanometer or an electronic null detector can be used.

Electronic Null Detector:

Sensitivity: 10 microvolts per meter division

Noise: Less than 5 microvolts

Galvanometer:

Sensitivity: 0.03 microampere per meter division

Critical Damping: 2 kilohms or more

1.2.3 For AC Measurements:

The ESI Model 860A or 861A AC Generator and Detector unit are recommended for use with the Model 290A Bridge. If other ac generator and detector units are used, they should meet the following specifications:

AC Generator

Desired characteristics:

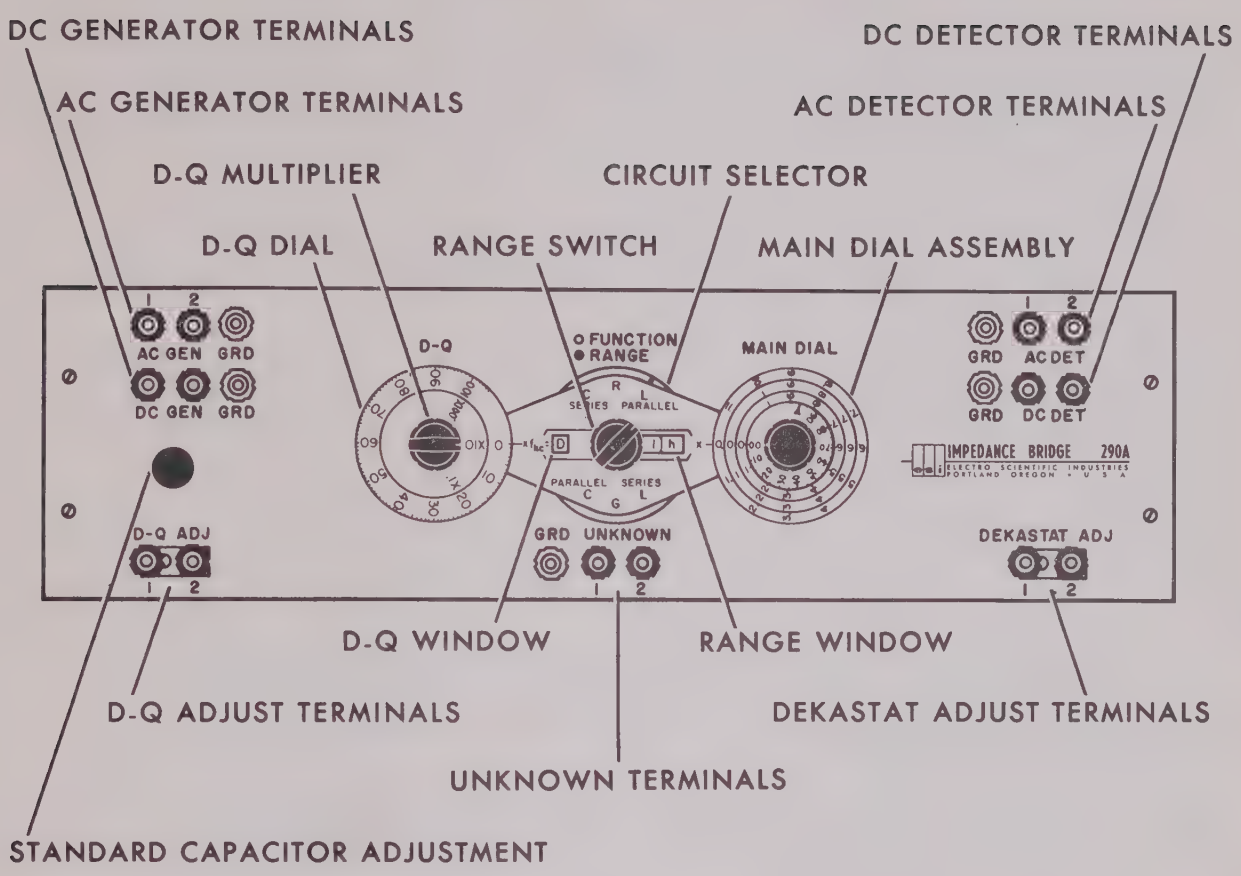
Frequency Range: 0.1 kc to 10 kc
Output Voltage: 0 to 20 volts open circuit
Series Protective Resistor: 100 ohms or more
Isolation: Capacitance of secondary to ground less than 30 pF
Direct capacitance secondary to primary less than 0.2 pF

AC Detector

Desired characteristics:

Sensitivity: 20 microvolts
Input Impedance: 500 kilohms
Harmonic Suppression: 30db by 2nd harmonic

2. CONTROLS



2.1 Circuit Selector: The large center dial selects the bridge circuit and connects the appropriate generator and detector.

Circuit		Measurement	Generator and Detector
1.	C_s	Series Capacitance	AC
2.	R^s	Resistance	DC
3.	L_p	Parallel Inductance	AC
4.	L^p	Series Inductance	AC
5.	G^s	Conductance	DC
6.	C_p	Parallel Capacitance	AC

The circuit in use is indicated by the mark at the edge of the selector switch. The electrical measurement unit is indicated in the right half of the right-hand window. For L or C measurements, the left-hand window shows whether the dissipation factor (D) or the storage factor (Q) is being measured.

2.2 Range Switch: The black center knob selects any of seven multipliers ranging from 10^{-4} to 100. The multiplier in use appears in the left half of the right-hand window.

2.3 Main Dial Assembly: The right-hand DEKASTAT dial reading times the range multiplier reading gives the value of resistance, conductance, inductance, or capacitance being measured.

2.4 D-Q Multiplier: The left-hand black knob selects the D-Q multiplier. The multiplying factor in use appears at the left of the D or Q value.

2.5 D-Q Dial: The reading of the large left-hand dial, times the D-Q multiplier reading, times the frequency in kilocycles gives the value of D or Q.

2.6 Unknown Terminals: The unknown component is connected to the two black terminals under the center dials. An adjacent metal ground terminal is provided for a shield connection.

2.7 Generator Terminals: The upper left-hand terminals are for connecting an external generator to the bridge. Separate terminals are provided for dc and ac connections. Ground terminals are provided for convenience.

2.8 Detector Terminals: The upper right-hand terminals are for connecting an external detector to the bridge. Separate terminals are provided for dc and ac connections. Ground terminals are provided for convenience.

2.9 D-Q Adjustment Terminals: The lower left-hand terminals are for attaching an external circuit element to the D-Q arm of the bridge for special measurements.

2.10 DEKASTAT Adjustment Terminals: The lower right-hand terminals are for attaching an external circuit element to the main dial DEKASTAT arm of the bridge for special measurements.

2.11 Standard Capacitor Adjustment: The left center hole cover conceals the adjusting screw for the standard capacitor. Setting this adjustment to give the correct bridge reading for an accurately known value of capacitance (0.1 μf recommended) assures a short term bridge accuracy rating improvement of 0.1% for all inductance and capacitance measurements.

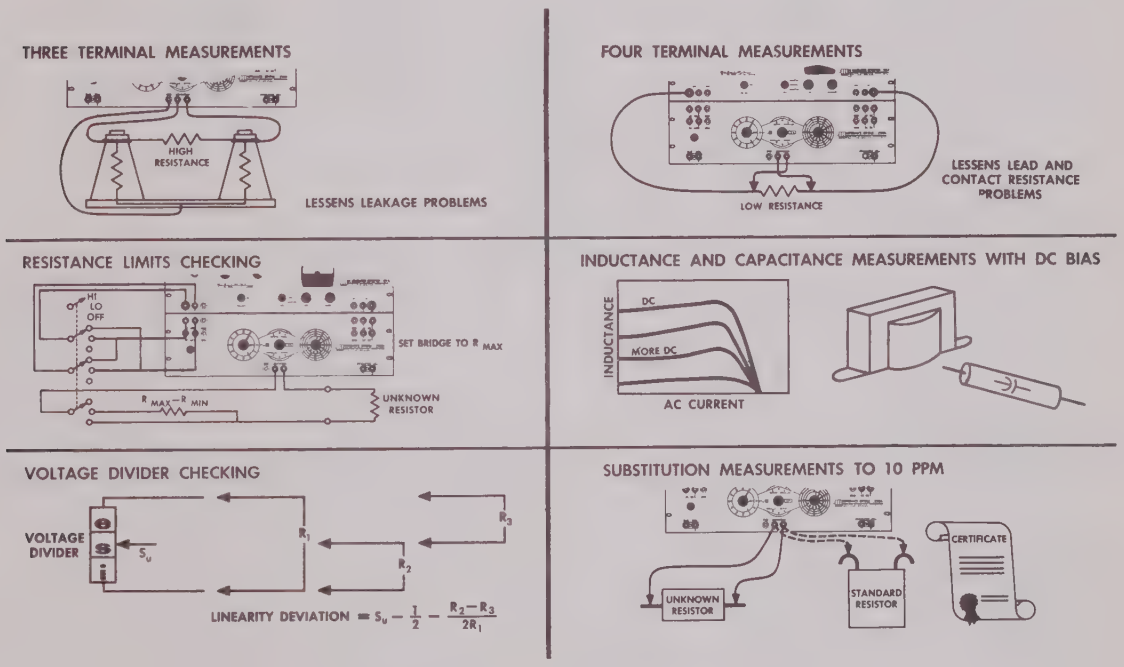
3. OPERATING INSTRUCTIONS

3.1 What the Bridge Measures

The ESI Model 290A Impedance Bridge measures resistance, conductance, inductance, and capacitance. It also measures the dissipation factor (D) and the storage factor (Q) of inductors and capacitors.

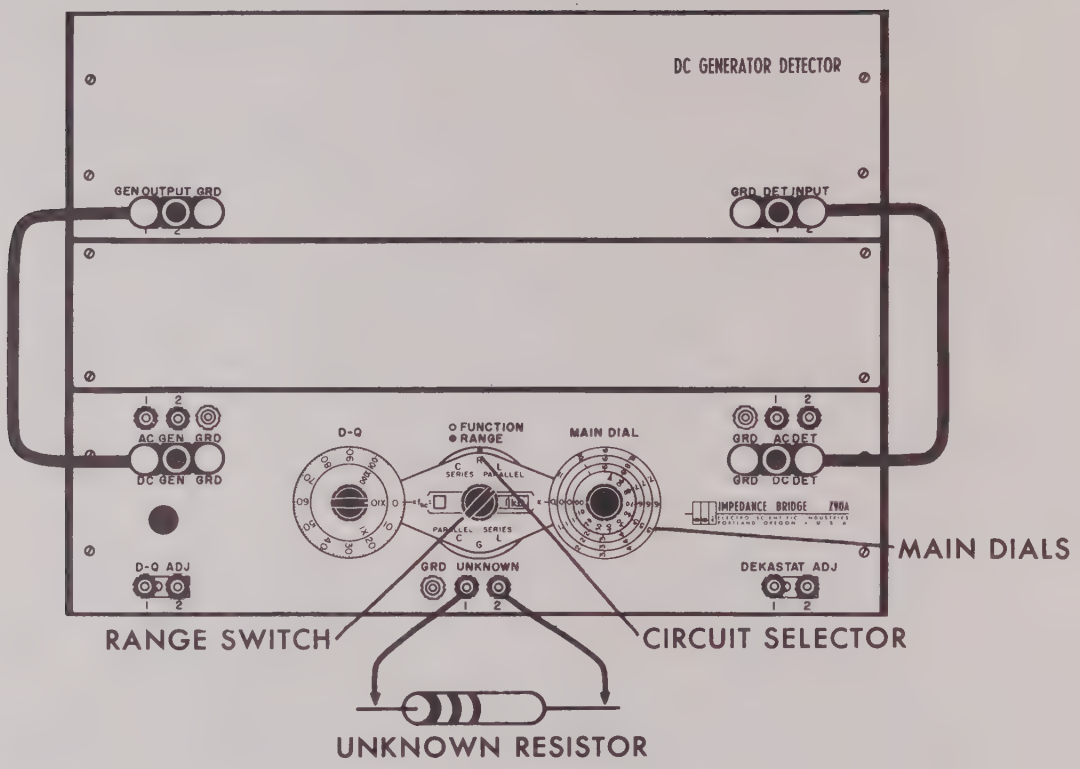
Resistance and conductance measurements are usually made with direct current because of the increased accuracy and the lack of hum pickup and stray capacitance effects. Resistance and conductance measurements can be made using ac, but they may require external reactance compensation.

Inductance and capacitance measurements are made in terms of a simple two-element circuit with the same impedance as the unknown. The bridge dials read the values of this equivalent circuit. To achieve highest measurement accuracy, an equivalent parallel circuit is used for high Q inductors and high D capacitors. An equivalent series circuit is used for low D capacitors and low Q inductors.



3.2 RESISTORS

3.2.1 MEASURING RESISTORS



CONNECT DC GENERATOR AND DETECTOR

WARNING: Limit the generator output to one watt maximum. Recommended ESI DC Generators and Detectors have this protective feature built in.

Connect the external dc generator and detector to the dc terminals. They will be connected to the correct bridge circuits by the circuit selector.

CONNECT RESISTOR TO UNKNOWN TERMINALS

Make good contact with the terminals.

SET CIRCUIT SELECTOR TO R OR G

$$R \text{ in kilohms} = \frac{1}{G \text{ in millimhos}}$$

If between 0.83 ohm and 1.2 megohms, measure either RESISTANCE or CONDUCTANCE. If less than 0.83 ohm (>1.2 mho), measure RESISTANCE. If greater than 1.2 megohms (<0.83 micromho), measure CONDUCTANCE.

3.2.1 MEASURING RESISTORS (Cont.)

SET POWER SUPPLY VOLTAGE AND DETECTOR SENSITIVITY (See above WARNING)	Set the detector sensitivity so that the pointer is about half-way between the center and one end of the scale. Set the generator resistance to give the most detector deflection for any unbalance. Set the generator power for the maximum power that will not harm the device being tested. Recommended ESI generators are power-limited at one watt, and most have adjustable output power. See the instruction manual for the applicable generator for details on power adjustment.
SET MAIN DIAL TO READ 3.0000	This setting makes it easier to find the correct range.
SET RANGE SWITCH FOR MINIMUM DETECTOR SIGNAL	This sets the range so that the value can be found with maximum resolution on the main dial.
ADJUST MAIN DIAL FOR NULL	Increase detector sensitivity as the null is approached. Recommended ESI generators and detectors cannot be damaged by normal bridge use at any setting. Be careful to avoid damage if any other detector is used.
IF THE MAIN DIAL READING IS LESS THAN 1.2000, USE THE NEXT LOWER RANGE AND READJUST MAIN DIAL FOR NULL	This takes advantage of the increased resolution near full scale of the dial.

3.2.2 THINGS TO WATCH OUT FOR

3.2.2.1 HIGH RESISTANCE MEASUREMENTS

Care must be taken to avoid leakage resistance across the unit being measured. If an electronic null detector is being used it may be affected by ac hum picked up by the leads.

3.2.2.2 LOW RESISTANCE MEASUREMENTS

On the low resistance ranges the lead resistance in the unknown arm becomes significant. A correction for this resistance can be made as follows:

1. Short the test leads together at the point that they are to be connected to the unknown resistor and measure this "ZERO RESISTANCE".

2. Connect the test leads to the unknown resistor and measure the "RESISTANCE READING".

3. The "RESISTANCE VALUE" of the unknown resistor is then the "RESISTANCE READING" minus the "ZERO RESISTANCE".

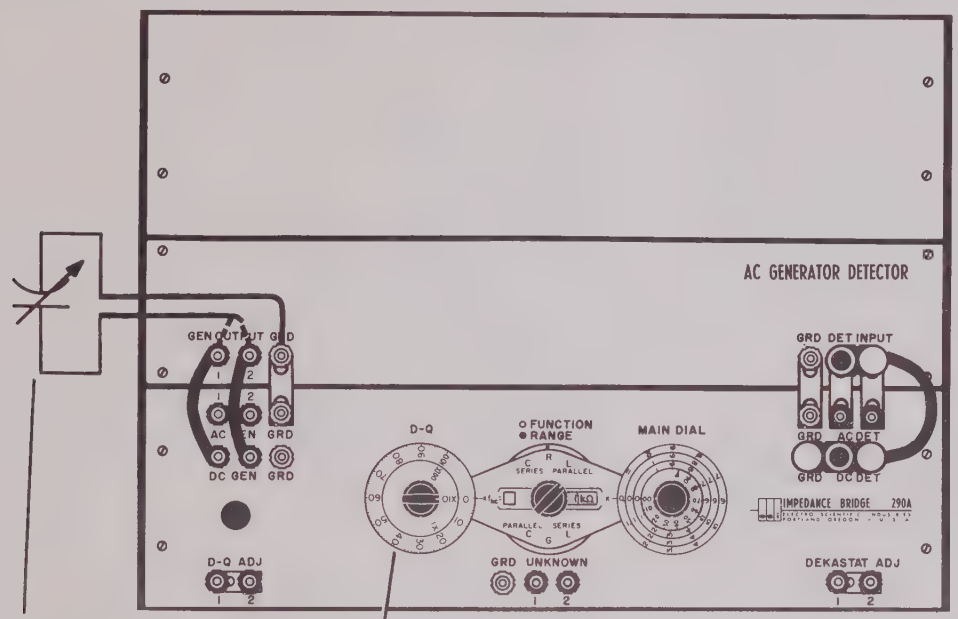
4. If the unknown resistance is to be connected directly to the terminals, the "ZERO RESISTANCE" reading can be taken by connecting a piece of heavy copper wire between the unknown resistance terminals. (#14 AWG copper wire has a resistance of about 0.00025 ohm/inch.)

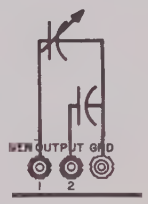
Sometimes thermal voltages are generated at connections and these can lead to erroneous balances of the bridge. If this condition is suspected, balance the bridge and then set the output switch to "reverse". If this results in a different galvanometer reading, change the main dial DEKASTAT® setting until the galvanometer reads the same for both output polarities. This cancels the effect of the thermal voltages.

3.2.3 MEASURING AC RESISTANCE

For greatest accuracy resistors should always be measured with dc. The accuracy of ac measurement will be 0.3% for one kilocycle and below over the range from one ohm to one megohm.

The indicated connections for the phase correction capacitor compensate for series inductance or parallel capacitance. It is impossible to seperate the correction for the unknown from that for the rest of the bridge circuit. If large reactances are involved the circuit should be measured as a capacitance or inductance and the resistance calculated.





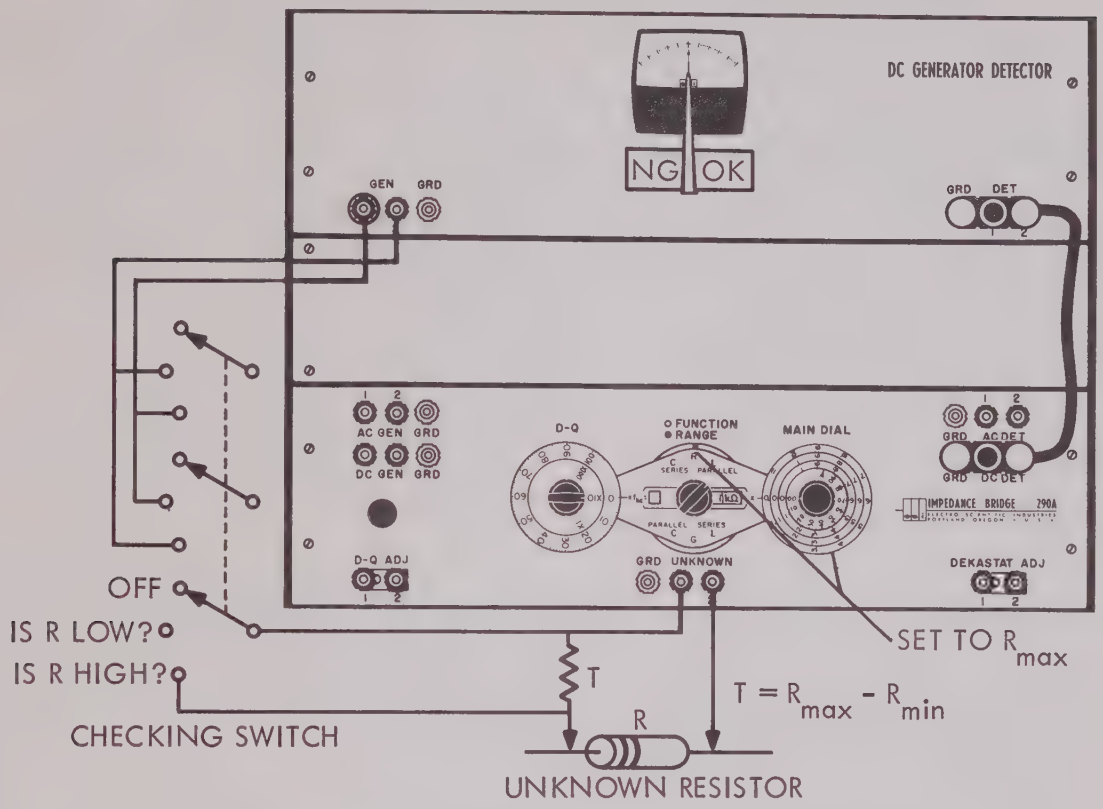
NOTE:
If the phase correction is small it may be convenient to connect a fixed capacitor to one terminal and a variable one to the other.

REMOVE THE AC GENERATOR CONNECTING STRAPS	The ac detector straps need not be removed
CONNECT THE BRIDGE DC GENERATOR AND DETECTOR TERMINALS TO THE AC GENERATOR AND DETECTOR	Short lengths of open-wire leads for the generator will minimize errors
SET THE BRIDGE ON THE R OR G RANGE	This connects the desired bridge circuit

TRY TO BALANCE THE BRIDGE AS WITH DC	Usually the eye will not completely open and/or the meter will not go completely to zero, thus indicating uncompensated phase shift
CONNECT A VARIABLE CAPACITOR FROM GROUND TO ONE OF THE GENERATOR TERMINALS AND TRY TO OBTAIN A NULL WITH IT AND THE MAIN DIALS.	Connecting the capacitor from ground to either generator terminal permits compensation for some of the possible circuits of the unknown.
IF A NULL CANNOT BE REACHED, CONNECT THE VARIABLE CAPACITOR BETWEEN THE OTHER GENERATOR TERMINAL AND GROUND. A NULL SHOULD BE OBTAINABLE WITH ONE CONNECTION OR THE OTHER.	This permits balance over the remaining possible circuit combinations. If a non linear element is being measured by ac a null balance may not be possible because the bridge will not be in balance at all parts of the cycle.
THE "RESISTANCE" VALUE AS READ WILL BE CORRECT FOR EQUIVALENT CIRCUITS CONSISTING OF A RESISTOR AND CAPACITOR IN PARALLEL OR A RESISTOR AND INDUCTOR IN SERIES.	R and G accuracy will be 0.3% or better for resistors between 1 ohm and 1 megohm at a frequency of 1 kc or less.

3.2.4 RESISTANCE LIMITS CHECKING

For rapidly checking resistance values between two tolerance limits.



3.2.4.1 BASIC INSTRUCTIONS

SET THE CIRCUIT SELECTOR TO R OR G. SET THE RANGE SWITCH AND MAIN DIAL DEKASTAT® TO THE UPPER RESISTANCE LIMIT.	These settings will allow checking both upper and lower limits.
CONNECT THE CIRCUIT AS SHOWN.	The generator reversal permits using the same direction of the null detector deflection for OK with both the upper and lower limit.
SHORT THE PROBES TOGETHER AND SHECK THE DIRECTION OF NULL DETECTOR DEFLECTION	The null detector should move to the right when the CHECKING SWITCH is in the IS R LOW? position. If it is not, reverse the polarity of the generator voltage or reverse the connections between the CHECKING SWITCH and the generator.
ATTACH THE PROBES TO THE UNKNOWN RESISTOR.	This completes the bridge circuit.

3.2.4.1 RESISTANCE LIMITS CHECKING (Cont.)

CHECK THE ZERO POSITION OF THE NULL DETECTOR.	The zero position may be adjusted by the null detector ZERO control.
FIND THE OPTIMUM SENSITIVITY SETTING BY TRIAL.	Start with minimum sensitivity. On the first resistance check, increase the detector sensitivity until the indication is nearly full scale. On each following test, reduce the sensitivity if the indication goes off scale to the right (OK) side; increase the sensitivity if the indication is close to zero.
SET THE CHECKING SWITCH TO "IS R LOW?".	If the null detector deflects to the right the unknown resistor is above the lower tolerance limit.
SET THE CHECKING SWITCH TO "IS R HIGH?".	If the null detector deflects to the right the unknown resistor is below the upper tolerance limit.

NOTE: If the resistance tolerance is given as $\pm\Delta\%$, the value of T will be $\frac{R2\Delta}{100}$ and R_{max} will be $\left(1 + \frac{\Delta}{100}\right) R$.

3.2.4.2 CHECKING HIGH RESISTANCE:

When checking high resistances, the voltage across the resistor will be high. The OFF position of the checking switch is provided to remove this voltage from the bridge while changing resistors.

3.2.4.3 CHECKING LOW RESISTANCE:

When checking low resistances the prove resistance R_o must be taken into account. It can be measured by shorting the probes. The bridge dials should be set to read $R_{max} + R_o$.

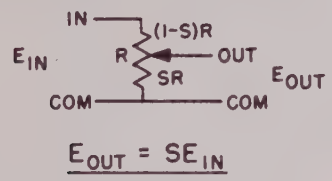
RESISTANCE LIMITS CHECKING

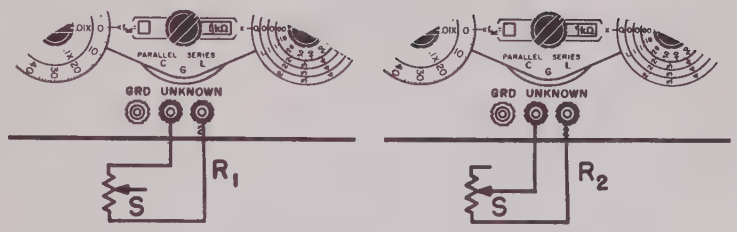
IF
$R_{MIN} < R < R_{MAX}$
AND IF
$T = R_{MAX} - R_{MIN}$
THEN
$(R_{MEAS}) < R_{MAX}$ Only if $R < R_{MAX}$
$(R_{MEAS} + T) > R_{MAX}$ Only if $R > R_{MIN}$

IF
$R(1+\Delta) = R_{MAX}$
$R(1-\Delta) = R_{MIN}$
THEN
$T = R2\Delta$

3.2.5 VOLTAGE DIVIDER CHECKING

3.2.5.1 SIMPLE TAPPED RESISTOR

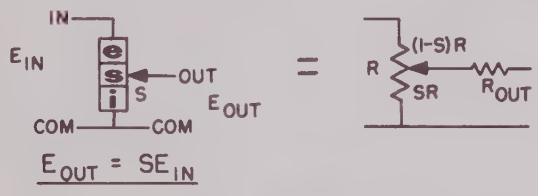


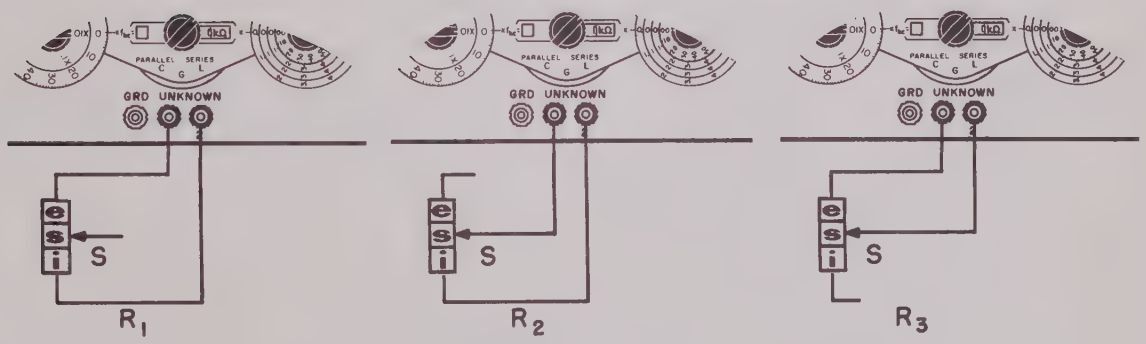


1. Follow the instructions for RESISTANCE measurement (3.2).
2. Measure R_1 between the input and common terminals.
3. Measure R_2 between the output and common terminals.
4. Calculate the divider setting S.

$$S = \frac{R_2}{R_1}$$

3.2.5.2 KELVIN VARLEY and other voltage divider types which may have equivalent resistance in the output lead.



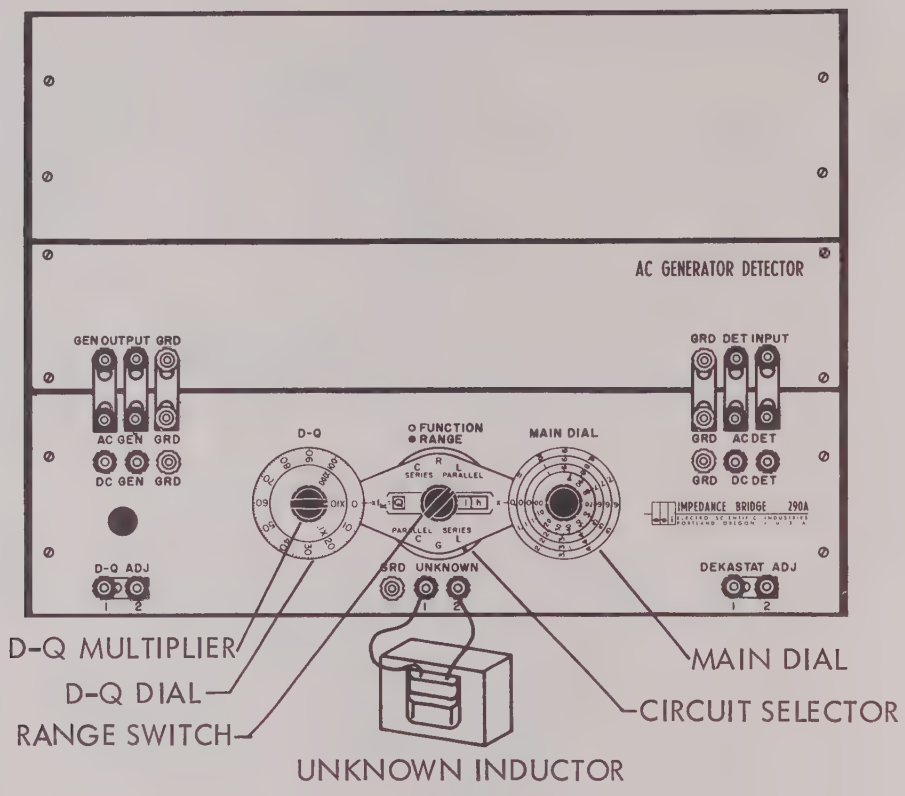


1. Follow the instructions for RESISTANCE measurement (3.2)
2. Measure R_1 between the input and common terminals.
3. Measure R_2 between the output and common terminals.
4. Measure R_3 between the input and output terminals.
5. Calculate the divider setting S.

$$S = \frac{1}{2} + \frac{R_2 - R_3}{2R_1}$$

3.3 INDUCTORS

3.3.1 MEASURING INDUCTORS



OPERATING INSTRUCTIONS

CONNECT AC GENERATOR AND DETECTOR

WARNING: Limit the generator output to one watt maximum. Recommended ESI AC Generators have this protective feature built in.

Connect the external generator and detector to the ac terminals. They will then be connected to the correct bridge circuits by the circuit selector.

CONNECT INDUCTOR TO UNKNOWN TERMINALS

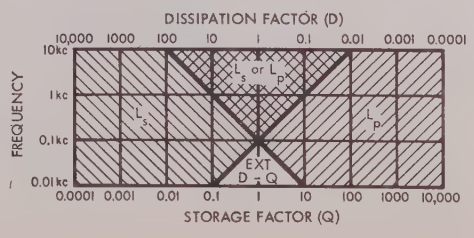
Make good contact with the terminals.

SET CIRCUIT SELECTOR TO L_p OR L_s

At 1 kc:

Use L_p for Q greater than 0.1

Use L_s for Q lower than 10



SET GENERATOR VOLTAGE AND DETECTOR GAIN

(See above WARNING)

SET MAIN DIAL TO READ 3.0000

SET D-Q MULTIPLIER TO .1x

SET D-Q DIAL TO:
0, IF BRIDGE MEASURES D,
OR 100, IF BRIDGE MEASURES Q

} These settings make it easier to find the correct range.

SET RANGE SWITCH FOR MINIMUM DETECTOR SIGNAL

This sets the range so that the value can be found with maximum resolution on the main dial.

ADJUST MAIN DIAL AND D-Q DIAL ALTERNATELY FOR NULL

IF THE MAIN DIAL READING IS LESS THAN 1.2000, USE NEXT LOWER RANGE AND READJUST MAIN DIAL FOR NULL

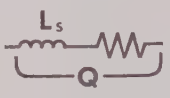
IF D-Q DIAL READING IS LESS THAN 10, USE NEXT LOWER SETTING OF D-Q MULTIPLIER AND READJUST D-Q DIAL FOR NULL

} This takes advantage of the increased resolution near full scale of the dials.

3.3.2 SERIES AND PARALLEL INDUCTANCE

The bridge measures a simple equivalent circuit for the impedance connected to its terminals. This equivalent circuit consists of either an inductance and resistance connected in series or a different inductance and resistance connected in parallel. The phase and magnitude of the resulting impedance are identical for both circuits. For values of Q less than 100 the series and parallel inductances differ measurably (by more than 0.01%).

WHEN THE BRIDGE MEASURES SERIES INDUCTANCE, L_s:



L_s = (range switch setting) x (main dial reading)

Q = (D-Q multiplier setting) x (D-Q dial reading) x (f_{kc})

$D = \frac{1}{Q}$

$R_s = \frac{1}{Q} \times 2\pi f L_s$

$Z = 2\pi f L_s (\frac{1}{Q} + j)$

Q and D in per unit
R_s in kilohms
f in kc
L_s in henrys
$j = \sqrt{-1}$
Z in kilohms

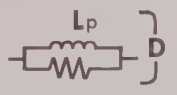
To calculate the equivalent parallel circuit:

The Q of the equivalent parallel circuit always equals the Q of the equivalent series circuit. The same is true of D.

$L_p = (1 + \frac{1}{Q^2}) \times L_s$

$R_p = Q \times 2\pi f L_p$

WHEN THE BRIDGE MEASURES PARALLEL INDUCTANCE, L_p:



L_p = (range switch setting) x (main dial reading)

D = (D-Q multiplier setting) x (D-Q dial reading) x (f_{kc})

$Q = \frac{1}{D}$

$R_p = \frac{1}{D} \times 2\pi f L_p$

$Z = \frac{2\pi f L_p (D+j)}{D^2 + 1}$

D and Q in per unit
R_p in kilohms
f in kc
L_p in henrys
$j = \sqrt{-1}$
Z in kilohms

To calculate the equivalent series circuit:

The D of the equivalent series circuit always equals the D of the equivalent parallel circuit. The same is true of Q.

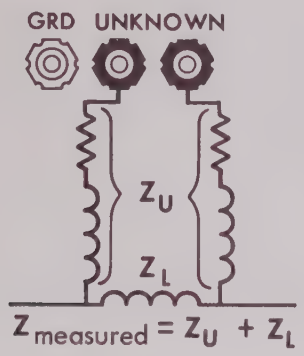
$L_s = \frac{1}{1 + D^2} \times L_p$

$R_s = D \times 2\pi f L_s$

3.3.3 THINGS TO WATCH OUT FOR

3.3.3.1 LOW INDUCTANCE MEASUREMENTS

The bridge measures the total impedance connected to its terminals. Both the unknown inductor and its leads contribute to this impedance. The leads have some resistance and inductance, which affect the value read from the bridge.



Z_U = Impedance of unknown inductor
Z_L = Impedance of leads

For greatest accuracy, minimize the lead impedance. Short heavy leads will reduce the resistance. Closely spaced twisted leads will reduce the inductance and the pickup of stray fields.

3.3.3.2 HIGH INDUCTANCE MEASUREMENTS

In making high inductance measurements, there are two things to watch out for:

1. Be careful to avoid hum pickup.
2. Keep the stray capacitance to a minimum.

To minimize both effects keep your hands as far as possible from the inductor measured.

Keep the leads as short and direct as possible. If extended leads are necessary, the lead from the center terminal should be shielded. See section 3.4.6 "Extended Leads".

Care should be taken to avoid coupling stray magnetic fields into the inductor being measured.

The D and Q readings on the highest L range will be in error as indicated in the specifications because of the residual capacitance of the range resistor. If accurate D or Q readings are needed the next lowest L range can be used. The L readings on the high range are accurate.

3.3.4 INDUCTANCE MEASUREMENTS WITH DC

3.3.4.1 WHEN TO USE DC

Iron core inductors are sensitive to both ac and dc current variations. Quantitative measurements of these effects can be made with the bridge.

3.3.4.2 THINGS TO WATCH OUT FOR

A. GENERAL PRECAUTIONS

Stray ac pickup may change sensitive components being measured or may give erroneous null detector readings.

The ac impedance of the dc external circuit must be greater than 2000 ohms for maximum sensitivity. If an isolating inductor is used to raise the ac impedance it may pick up stray signals or may have mutual coupling with the unknown inductor being measured. Either one may cause reading errors. Such an inductor should be well shielded magnetically and be placed to minimize its chance of interfering. For low currents isolation may be accomplished with a resistor instead of the inductor.

The parallel inductance circuit is recommended because it simplifies dc current measuring and bridge protection problems. With the series circuit the dc current divides between the bridge arms so that it is difficult to meter. The series circuit would also require a more careful analysis to avoid excessive current in any of the bridge arms.

If equivalent series inductance is required it can be easily calculated from the parallel inductance and D (See Sec. 3.3.2).

If D is too high to be read directly, an external rheostat such as the ESI Model DB 655 DEKASTAT®, connected to the D-Q ADJ terminals can be used to extend the D range. D can be calculated by the equation:

$$D = D_{reading} + 0.628\, R_{k\Omega}\, f_{kc}$$

where:

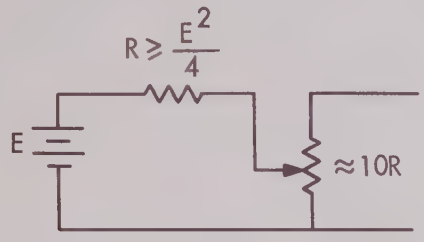
D	-	Dissipation factor of unknown
$D_{reading}$	-	Bridge D reading
R	-	External rheostat resistance in kilohms
f_{kc}	-	Operating frequency in kilocycles

B. WITH DC SUPPLIED THROUGH THE GENERATOR TERMINALS

Supplying the dc signal through the generator terminals allows more current for measuring inductors below 1.2 millihenrys. With this connection the dc current is not affected by balancing the bridge. A grounded dc generator cannot be used

because one of the detector terminals is grounded. Leakage capacitance and resistance from the dc source to ground will be across bridge arms and may cause significant errors.

If accuracy better than 0.1% is not required, the recommended ESI dc generators can be used in this application. They can be used without any additional equipment except an isolating capacitor, which is shown in the accompanying connection diagrams. If higher accuracy is required, a power-limited battery circuit that is well insulated from ground and has less than 10 pF capacitance to ground is recommended. The following circuit illustrates a power-limited variable circuit that has a maximum output power of 1 watt which will not damage the bridge under any conditions.



With the parallel inductance circuit the standard capacitor blocks the dc from all of the bridge arms except the inductor being measured and the range resistor. As a result the maximum allowable current will be limited by the range resistor. This current limit is shown in Section 3.3.4.3.

C. WITH DC SUPPLIED THROUGH THE DETECTOR TERMINALS

Supplying the dc signal through the detector terminals allows the use of higher current in measuring inductors above 1.2 millihenrys but the dc current will be influenced by the main dial DEKASTAT setting.

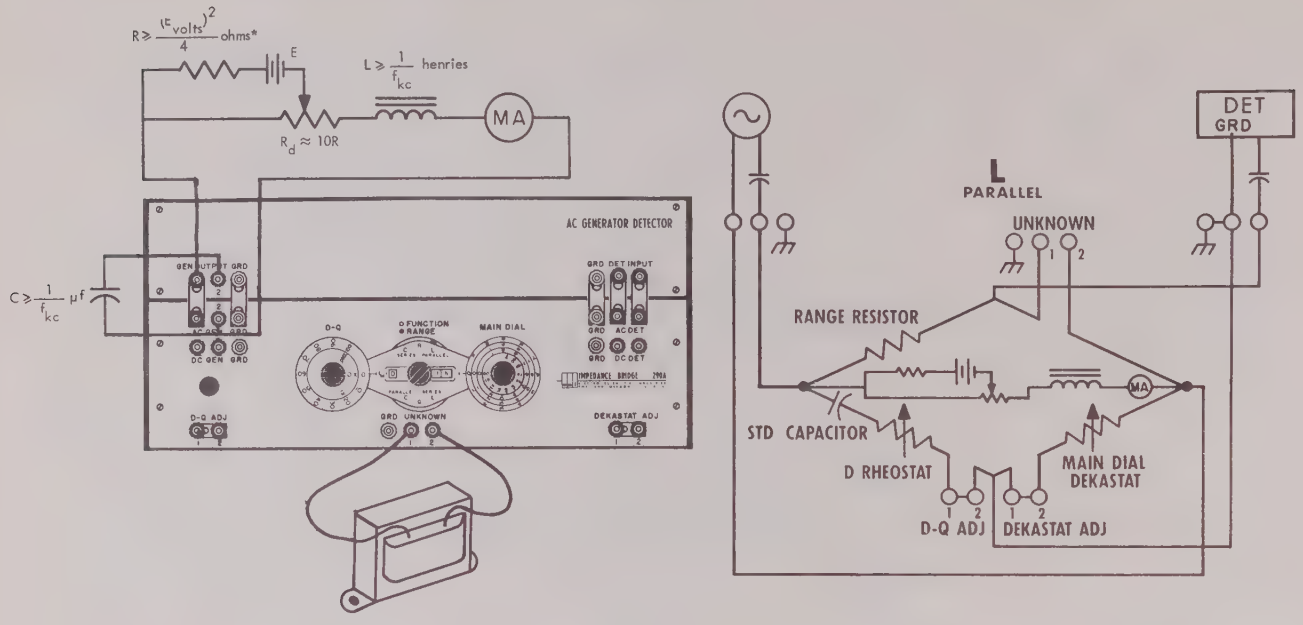
Since one of the detector terminals is normally grounded in recommended ESI detectors, a grounded power supply can be used.

The problems resulting from stray ac pickup either from the ripple of a dc supply, capacitive coupling to power lines or the bridge generator, stray field pickup by the isolating inductor (if used), or inductive coupling to the unknown inductor, are much more serious with this connection because of the direct coupling to the detector.

In this circuit the current goes through the unknown inductor and the main dial DEKASTAT. It must be limited by the values given in Section 3.3.4.4. If more current is needed the range can be increased by one setting and the first DEKASTAT dial turned to zero. This will decrease the DEKASTAT resistance and increase its current rating. Because of the high resolution of the main dial DEKASTAT accurate measurements are possible even when the first dial is not used. By setting the first two dials to zero higher current is possible but only 100 divisions of resolution are left.

3.3.4 INDUCTANCE MEASUREMENT WITH DC (cont'd.)

3.3.4.3 For parallel inductance measurement with dc superimposed through the generator terminals.



CONNECT AS SHOWN

E	- VOLTAGE SOURCE	The detector input should have an isolating capacitor. This capacitor is built into the recommended ESI Detectors.
R	- POWER LIMITING RESISTOR	Protects the bridge, detector and unknown inductor.
L	- ISOLATING INDUCTOR	Avoid ac pickup and coupling to the unknown. Prevents excessive generator loading. Not necessary if R ⩾ 100 ohms.
C	- ISOLATING CAPACITOR	Keeps dc out of the Generator.
R_d	- CURRENT ADJUSTING CONTROL	To set desired current.
MA	- CURRENT MONITORING METER	To measure dc current.

ADJUST THE DC CURRENT AS REQUIRED

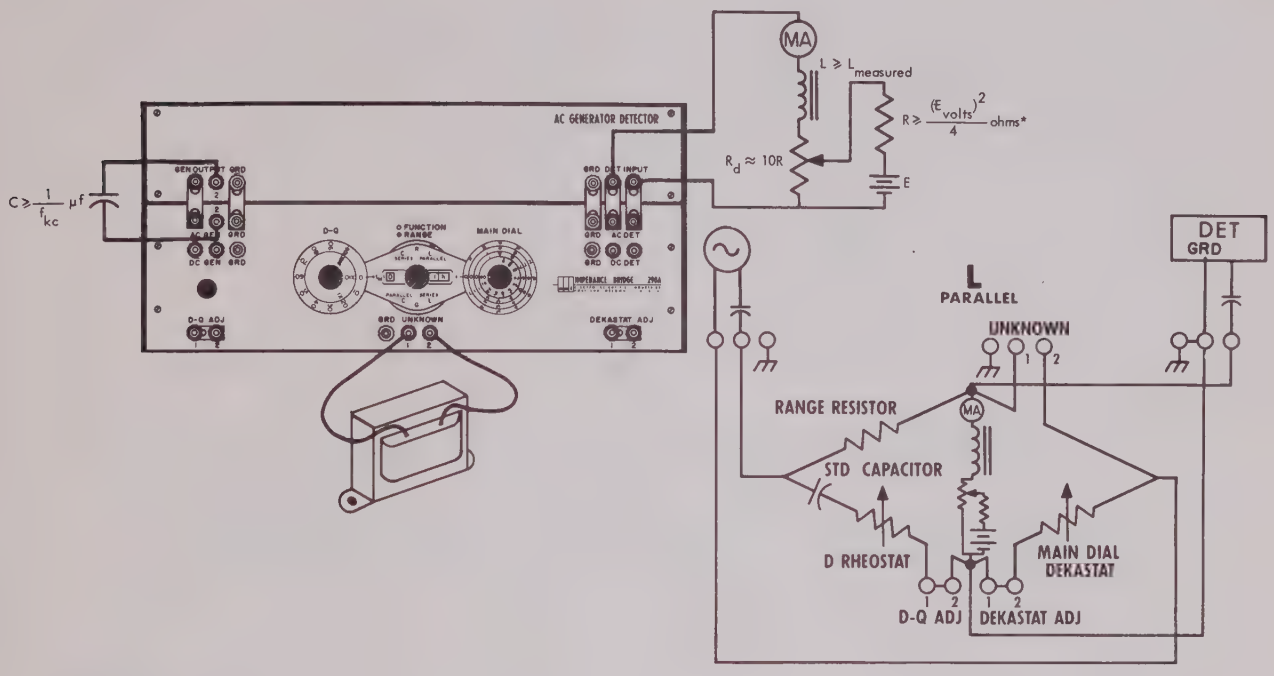
MEASURE THE INDUCTANCE — See Section 3.3

*This limits to one watt the dc power which can be supplied to the bridge thus protecting all of the bridge circuit. With care more current and voltage can be applied. The current rating of the bridge is given in the table below. These values should never be exceeded.

RANGE	UNKNOWN INDUCTANCE	MAXIMUM CURRENT
10^{-4}	0.1 μh to 1.2 mh	710 ma
10^{-3}	1 μh to 12 mh	230 ma
10^{-2}	10 μh to 120 mh	71 ma
10^{-1}	100 μh to 1.2 h	23 ma
1	1 mh to 12 h	7.1 ma
10	10 mh to 120 h	2.3 ma
100	100 mh to 1200 h	250 μa

3.3.4 INDUCTANCE MEASUREMENT WITH DC (cont'd.)

3.3.4.4 For parallel inductance measurements with dc superimposed through the detector terminals.



CONNECT AS SHOWN

E - VOLTAGE SOURCE	The detector input should have an isolating capacitor. This capacitor is built into the recommended ESI Detectors.
R - POWER LIMITING RESISTOR	Protects bridge, detector and unknown inductor.
L - ISOLATING INDUCTOR	Avoid ac pickup and coupling to the unknown. Prevents excessive generator loading. Not necessary if $R \geq (L_{h\text{-measured}})(f_{kc})(6)$ kilohms.
C - ISOLATING CAPACITOR	Keeps dc out of the Generator
R_d - CURRENT ADJUSTING CONTROL	To set desired current.
MA - CURRENT MONITORING METER	To measure dc current.

ADJUST THE DC CURRENT AS REQUIRED — The current will vary with the setting of the main dial.

MEASURE THE INDUCTANCE — See Section 3.3

*This limits to one watt the dc power which can be supplied to the bridge thus protecting all of the bridge circuit. With care more current and voltage can be applied. The current ratting of the bridge is given in the table below. The outer dial must be set to zero to use the "2nd" dial rating. Both outer dials must be set to zero to use the "3rd" dial rating. All three decades must be set to zero to use the rheostat rating. These values should never be exceeded.

RESOLUTION	DIAL	UNKNOWN INDUCTANCE**	MAXIMUM CURRENT
120,000 div	OUTER	100.0 μh to 1200 h	23 ma
10,000 div	2nd	10.0 μh to 100 h	71 ma
1,000 div	3rd	1.0 μh to 10 h	230 ma
105 div	RHEOSTAT	0.01 μh to 1.05 h	230 ma

**Lower limit is one division on dial which limits current on lowest range.

3.3.5 AC VOLTAGE MEASUREMENT

To measure the ac voltage applied to the unknown inductor:

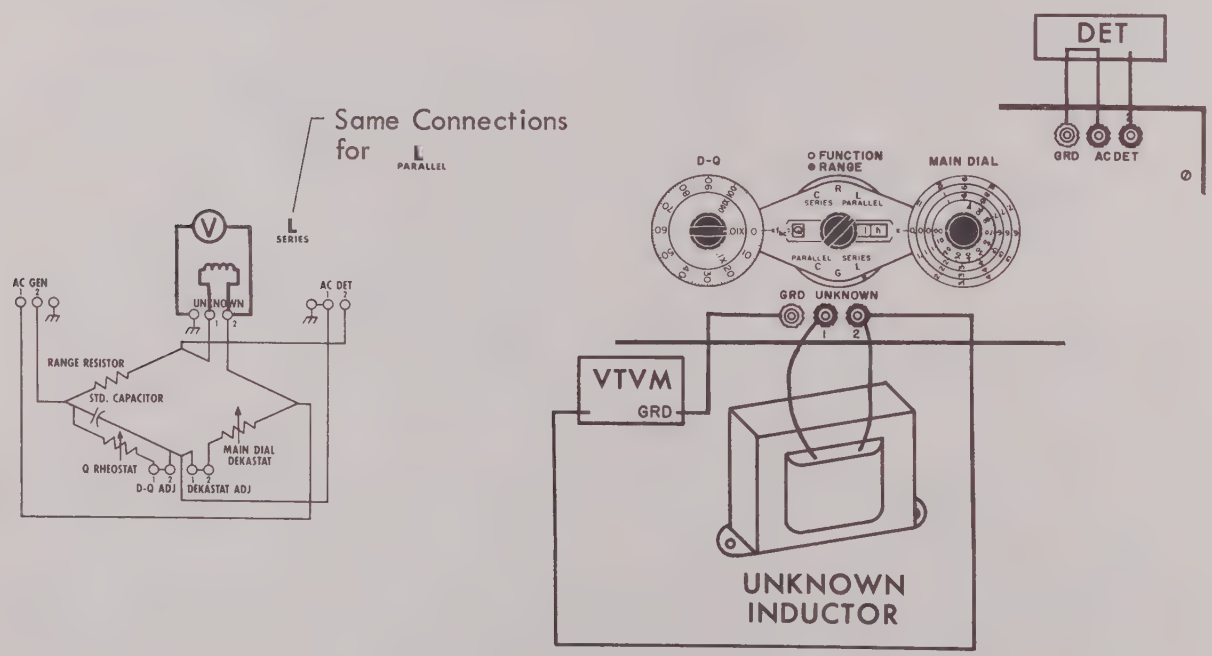
Connect ac detector terminal No. 1 to ground. This is done internally in recommended ESI Detectors. To prevent ground loops do not make any assitional connections.

Connect the ground terminal of a high impedance ac voltmeter to a ground terminal of the bridge.

Connect the input terminal of the voltmeter to unknown terminal No. 2 of the bridge.

Balance the bridge.

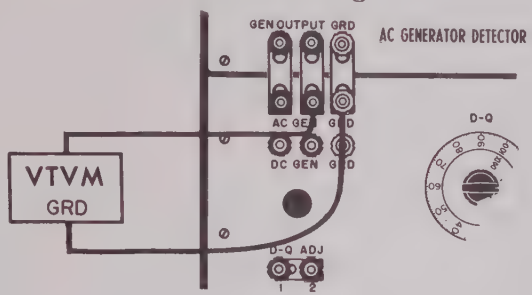
Read the voltmeter. With the bridge balanced, this voltage is equal to the ac voltage across the unknown inductor, but the inductor has not been loaded by the voltmeter. The bridge readings, however, may be incorrect while the meter is connected. Disconnect the voltmeter and balance the bridge again to measure inductance correctly.



3.3.6 AC CURRENT MEASUREMENT

To measure the ac current supplied to the unknown inductor:

The ac voltage across the range resistor is proportional to the ac current through the unknown. At balance this voltage is equal to the voltage across the standard capacitor arm which can be measured with a grounded voltmeter.



Connect ac detector terminal No. 1 to ground. This is done internally in the recommended ESI Detectors. To prevent ground loops do not make any additional connections.

Connect the ground terminal of a high impedance sensitive ac vacuum tube voltmeter to the ground terminal of the bridge.

Connect the input terminal of the voltmeter to AC GEN terminal No. 2 of the bridge.

Balance the bridge using either the series or parallel inductance circuit.

Read the voltmeter. The ac current in milliamperes will be equal to the voltage read (in volts) times the multiplier M from the following table.

$$I = V \times M$$

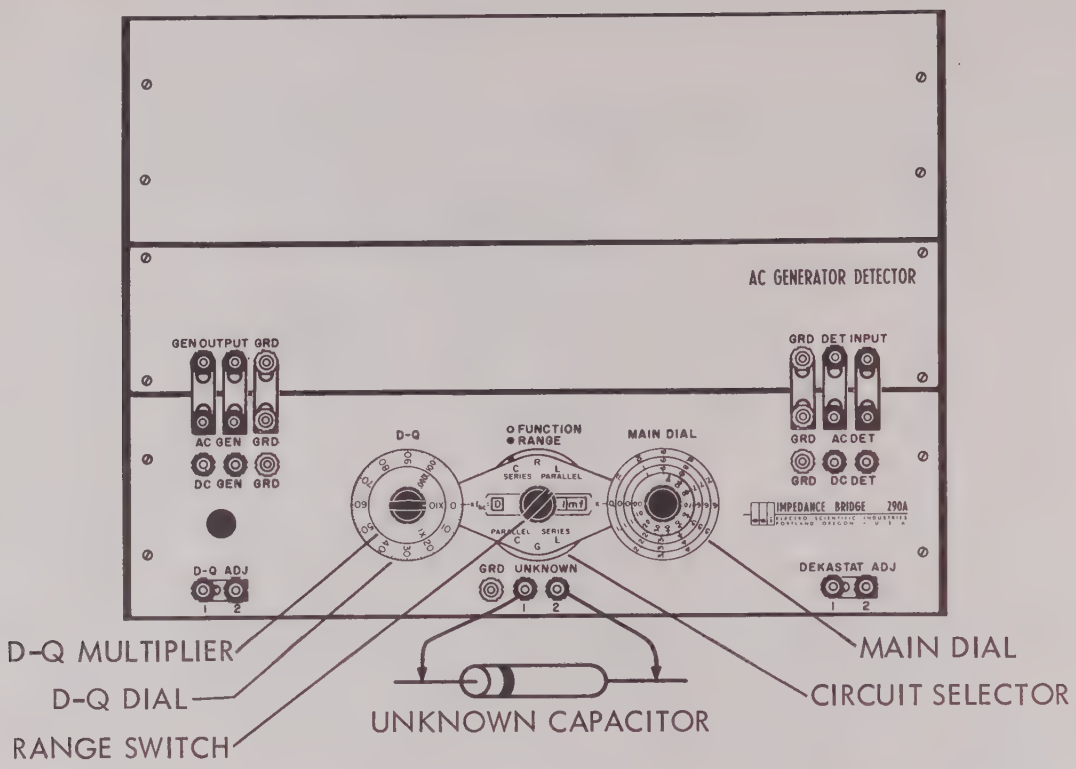
I - current in milliamperes
V - voltmeter reading in volts
M - multiplier from table

RANGE	UNKNOWN INDUCTANCE	M
10^{-4}	0.1 µh to 1.2 mh	1000
10^{-3}	1 µh to 12 mh	100
10^{-2}	10 µh to 120 mh	10
10^{-1}	100 µh to 1.2 h	1
1	1 mh to 12 h	0.1
10	10 mh to 120 h	0.01
100	100 mh to 1200 h	0.001

Remove the voltmeter and re-balance the bridge for the precise inductance measurement.

3.4 CAPACITORS

3.4.1 MEASURING CAPACITORS



OPERATING INSTRUCTIONS

CONNECT AC GENERATOR AND DETECTOR

Connect the external generator and detector to the ac terminals. They will then be connected to the correct bridge circuits by the circuit selector.

WARNING: Limit the generator output to one watt maximum. Recommended ESI AC Generators have this protective feature built in.

CONNECT CAPACITOR TO UNKNOWN TERMINALS

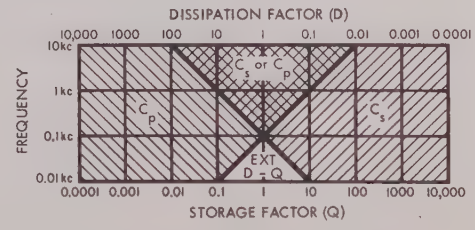
To minimize stray capacitance to ground, connect the outside foil to the left hand terminal.

SET THE CIRCUIT SELECTOR TO C_s OR C_p

At 1 kc:

Use C_p for D greater than 0.1

Use C_s for D lower than 10



Range of D and Q covered by C_s and C_p circuits.

SET GENERATOR VOLTAGE AND DETECTOR GAIN

(See Above WARNING)

SET MAIN DIAL TO READ 3.0000

SET D-Q MULTIPLIER TO .1x

SET D-Q DIAL TO
0, IF BRIDGE MEASURES D, OR
100, IF BRIDGE MEASURES Q

These settings make it easier to find the correct range.

SET THE RANGE SWITCH FOR MINIMUM DETECTOR SIGNAL

This sets the range so that the value can be found with maximum resolution on the main dial.

ADJUST MAIN DIAL AND D-Q DIAL ALTERNATELY FOR NULL

IF THE MAIN DIAL READING IS LESS THAN 1.2000, USE NEXT LOWER RANGE AND READJUST MAIN DIAL FOR NULL

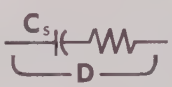
IF D-Q DIAL READING IS LESS THAN 10, USE NEXT LOWER SETTING OF D-Q MULTIPLIER AND READJUST D-Q DIAL FOR NULL

This takes advantage of the increased resolution near full scale of the dials.

3.4.2 SERIES AND PARALLEL CAPACITANCE

The bridge measures a simple equivalent circuit for the impedance connected to its terminals. This equivalent circuit consists of either a capacitance and resistance connected in series or a different capacitance and resistance connected in parallel. The phase and magnitude of the resulting impedance are identical for both circuits. For values of D greater than 0.01 the series and parallel capacitances differ measurably (by more than 0.01%).

WHEN THE BRIDGE MEASURES SERIES CAPACITANCE, C_s:



C_s = (range switch setting) x (main dial reading)

D = (D-Q multiplier setting) x (D-Q dial reading) x (f_{kc})

$Q = \frac{1}{D}$

$R_s = \frac{D}{2\pi f C_s}$

$Z = \frac{D - j}{2\pi f C_s}$

D and Q in per unit
R_s in kilohms
f in kc
C_s in microfarads
$j = \sqrt{-1}$
Z in kilohms

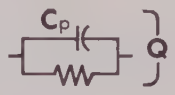
To calculate the equivalent parallel circuit:

The D of the equivalent parallel circuit always equals the D of the equivalent series circuit. The same is true of Q.

$C_p = \frac{C_s}{(1 + D^2)}$

$R_p = \frac{1}{D} \times \frac{1}{2\pi f C_p}$

WHEN THE BRIDGE MEASURES PARALLEL CAPACITANCE, C_p:



C_p = (range switch setting) x (main dial reading)

Q = (D-Q multiplier) x (D-Q dial reading) x (f_{kc})

$D = \frac{1}{Q}$

$R_p = \frac{Q}{2\pi f C_p}$

$Z = \frac{\frac{1}{Q} - j}{2\pi f C_p (1 + \frac{1}{Q^2})}$

Q and D in per unit
R_p in kilohms
f in kc
C_p in microfarads
$j = \sqrt{-1}$
Z in kilohms

To calculate the equivalent series circuit:

The Q of the equivalent series circuit always equals the Q of the equivalent parallel circuit. The same is true of D.

$C_s = (1 + \frac{1}{Q^2}) \times C_p$

$R_s = \frac{1}{Q} \times \frac{1}{2\pi f C_s}$

3.4.3 THINGS TO WATCH OUT FOR

3.4.3.1 LOW CAPACITANCE MEASUREMENTS

In making low capacitance measurements, there are two things to watch out for:

1. Be careful to avoid hum pickup.
2. Keep the stray capacitance to a minimum.

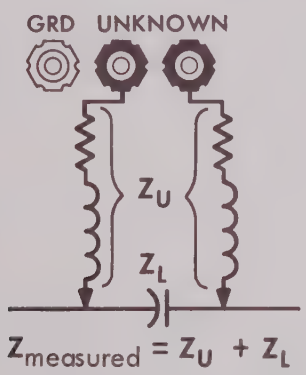
To minimize both effects, keep your hands as far as possible from the capacitor being measured.

Keep the leads as short and direct as possible. If extended leads are necessary, the lead from the center terminal should be shielded. See section 3.4.6, "Extended Leads".

The D and Q readings on the lowest C range will be in error as indicated in the specifications because of the residual capacitance of the range resistor. If accurate D or Q readings are needed the next highest C range can be used. The C readings on the low range are accurate.

3.4.3.2 HIGH CAPACITANCE MEASUREMENTS

The bridge measures the total impedance connected to its terminals. Both the unknown capacitor and its leads contribute to this impedance. The leads have some resistance and inductance, which affect the value read from the bridge.



Z_U = Impedance of unknown capacitor

Z_L = Impedance of leads

For the greatest accuracy, minimize the lead impedance. Short heavy leads will reduce the resistance. Closely spaced twisted leads will reduce the inductance and the pickup of stray fields.

3.4.4 CAPACITANCE MEASUREMENT WITH DC

3.4.4.1 WHEN TO USE DC

Some capacitors need a polarizing voltage. For example, electrolytic and tantalytic capacitors can be damaged by the reverse polarity half-cycle of the test frequency. Even if the capacitors are not damaged, erroneous readings may result.

A polarizing voltage is not always needed in these measurements. If the ac voltage is kept at a very low value (typically below one-half volt), the capacitor will not be damaged, and the readings will be reasonably accurate.

3.4.4.2 THINGS TO WATCH OUT FOR

Stray ac pickup may change sensitive components being measured or may give erroneous null detector readings.

The ac impedance of the external dc circuit must be less than 200 ohms for maximum sensitivity.

The series capacitance circuit is recommended because it simplifies dc voltage protection and measuring problems. With the parallel circuit the dc voltage divides between the bridge arms so that it is difficult to meter. This also requires a more careful analysis to avoid excessive voltage across any of the bridge arms.

If equivalent parallel capacitance is required it can be easily calculated from the series capacitance and D. See section 3.4.2.

If D is too high to be read directly, an external rheostat such as the ESI Model DB 655 DEKASTAT®, connected to the D-Q ADJ terminals can be used to extend the D range. If the series capacitance circuit is used, D can be calculated by the equation:

$$D = D_{reading} + \frac{R}{1.592\, f_{kc}}$$

where:

D	-	Dissipation factor of unknown capacitor
$D_{reading}$	-	D Reading of bridge
R	-	External rheostat resistance in kilohms
f_{kc}	-	Operating frequency in kilocycles

3.4.4.2 THINGS TO WATCH OUT FOR (cont'd.)

If the equivalent series resistance of the capacitor being measured is much greater than the resistance of the range resistor most of the dc input voltage will appear across the unknown capacitor. If the dc resistance of the unknown capacitor is known the voltage across it will be shown by the following equation:

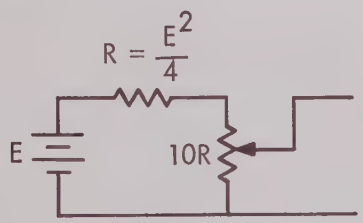
$$E_c = E_{in} \frac{R_c}{R_c + R_R}$$

where:

E_c - DC voltage across the unknown capacitor
E_{in} - DC voltage at the generator terminals
R_c - DC resistance of the unknown capacitor
R_R - Resistance of the range resistor

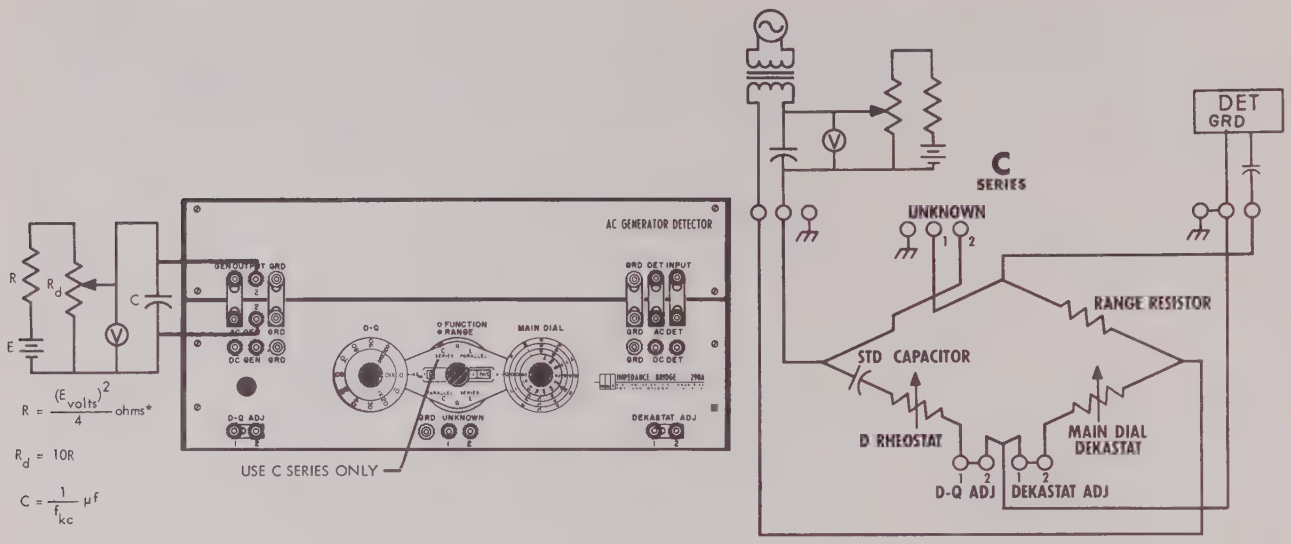
A grounded dc generator cannot be used because one of the detector terminals is grounded. Leakage capacitance and resistance from the dc source to ground will be across bridge arms and may cause significant errors.

If accuracy better than 0.1% is not required, the recommended ESI dc generators can be used in this application. They can be used without any additional equipment except an isolating capacitor, which is shown in the accompanying connection diagrams. If higher accuracy is required, a power-limited battery circuit that is well insulated from ground and has less than 10 pF capacitance to ground is recommended. The following circuit illustrates a power-limited variable circuit that has a maximum output power of 1 watt which will not damage the bridge under any conditions.



With the series inductance circuit the standard capacitor is subjected to the same dc voltage as the unknown capacitor. As a result the maximum allowable voltage must be limited to the standard capacitor rating of 300 volts.

3.4.4.3 FOR SERIES CAPACITANCE MEASUREMENTS WITH SUPERIMPOSED DC:



CONNECT THE CIRCUIT AS SHOWN	The detector input should have an isolating capacitor. This capacitor is built into recommended ESI Detectors.
E - DC VOLTAGE SOURCE	Battery recommended to avoid stray pickup and leakage
R - POWER LIMITING RESISTOR $R = \frac{(E_{volts})^2}{4}$ ohms*	This protects the bridge in case the unknown terminals are shorted.
R_D - VOLTAGE ADJUSTING CONTROL	This sets the dc voltage.
CONNECT THE METER "V" IN PARALLEL WITH THE DC SUPPLY	The impedance of most meters is high enough so that they will not load the dc supply.
ADJUST THE DC VOLTAGE AS REQUIRED	For low leakage capacitors the voltage across the unknown capacitor will be equal to the voltmeter "V" reading.
MEASURE THE CAPACITANCE	See section 3.3.4.

*This limits the dc power that can be supplied to the bridge to one watt to protect all of the bridge circuit in case the unknown capacitor is accidentally shorted. The maximum dc supply should not exceed 300 volts for the protection of the standard capacitor.

3.4.5 AC VOLTAGE MEASUREMENT

To measure the ac voltage applied to the unknown capacitor:

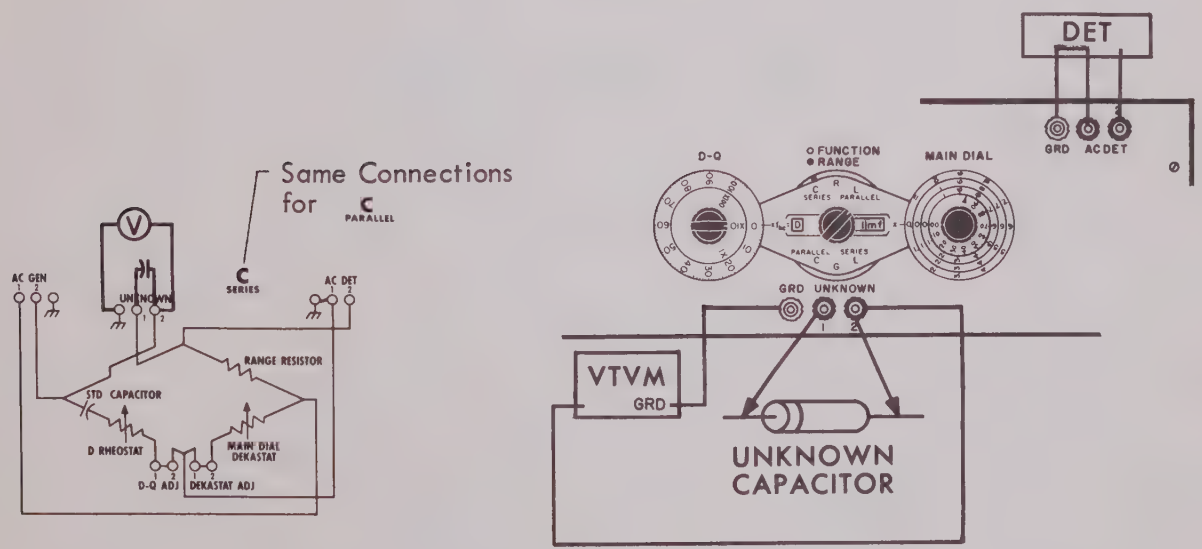
Connect ac detector terminal No. 1 to ground. This is done internally in recommended ESI Detectors. To prevent ground loops do not make any additional connections.

Connect the ground terminal of a high impedance ac voltmeter to the ground terminal of the bridge.

Connect the input terminal of the voltmeter to unknown terminal No. 2 of the bridge.

Balance the bridge.

Read the voltmeter. With the bridge balanced, this voltage is equal to the ac voltage across the unknown capacitor, but the capacitor has not been loaded by the voltmeter. The bridge readings, however, may be incorrect while the meter is connected. For the correct capacitance reading, disconnect the voltmeter from terminal No. 2 and rebalance the bridge.



3.4.6 EXTENDED LEADS

Sometimes it is necessary to use extended leads. This can be done easily without causing error in the measurement.

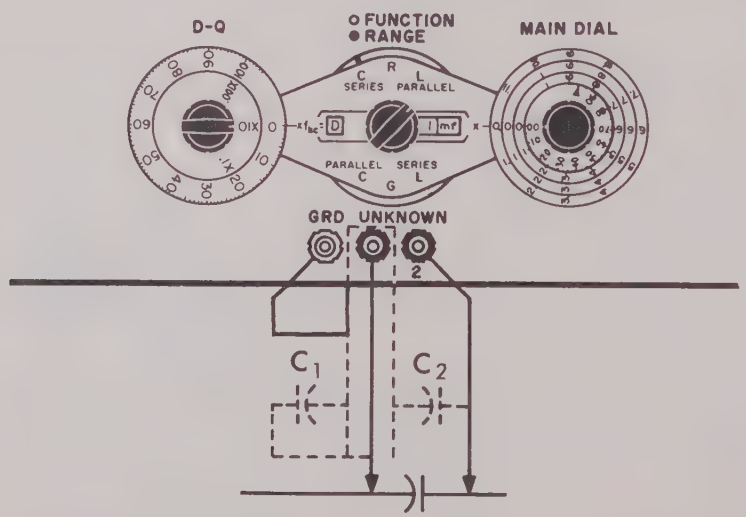
Connect a shielded lead to Unknown terminal No. 1.

Connect the shield of this lead to the adjacent GRD terminal of the bridge.

Connect an unshielded lead to Unknown terminal No. 2.

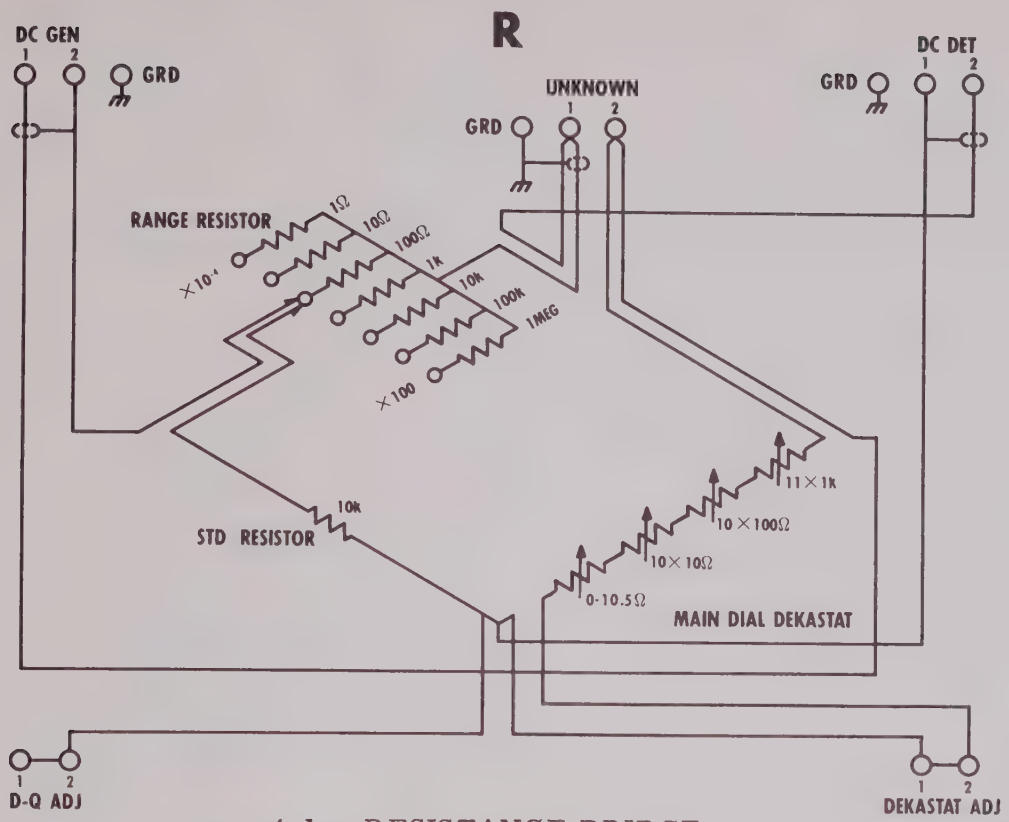
The capacitance between the shield and the center conductor is now across the detector. This keeps it from causing any error. If this stray capacitance is greater than 500 pF, it may reduce the detector sensitivity.

The stray capacitance from the unshielded lead to ground is across the standard capacitance arm of the bridge. As the standard capacitor is 100,000 pF, the stray capacitance will not cause significant errors unless it exceeds a few 10's of pF.

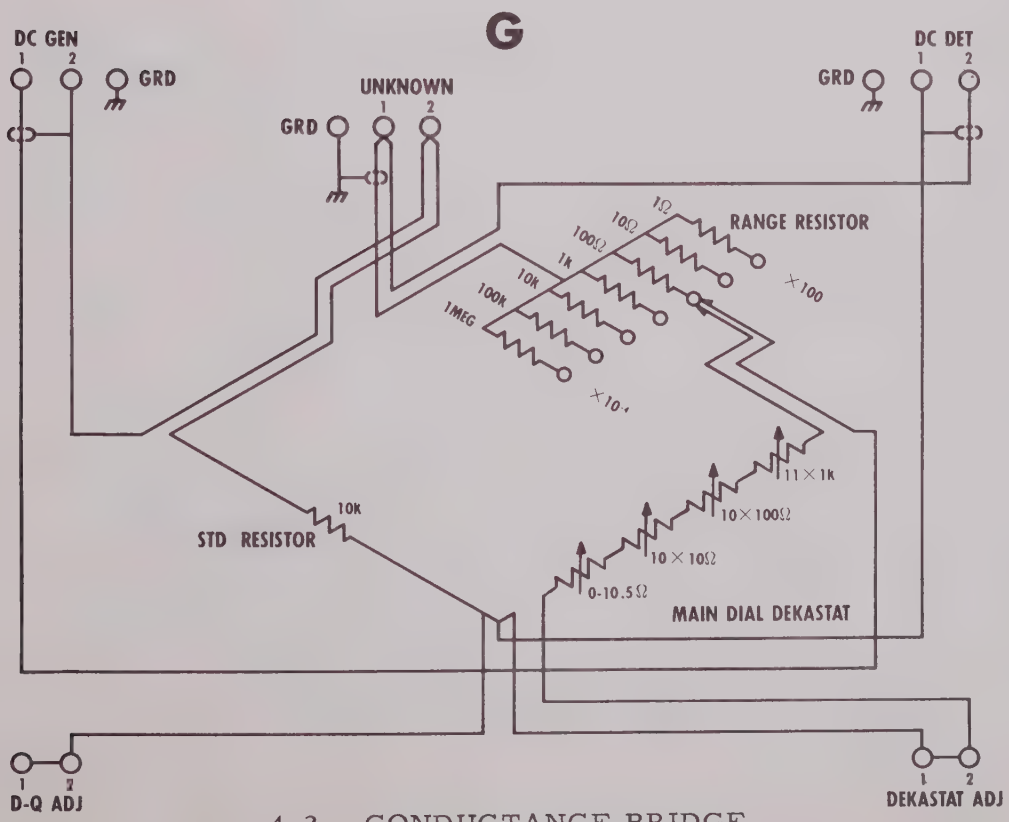


C_1 = Capacitance from center conductor to ground

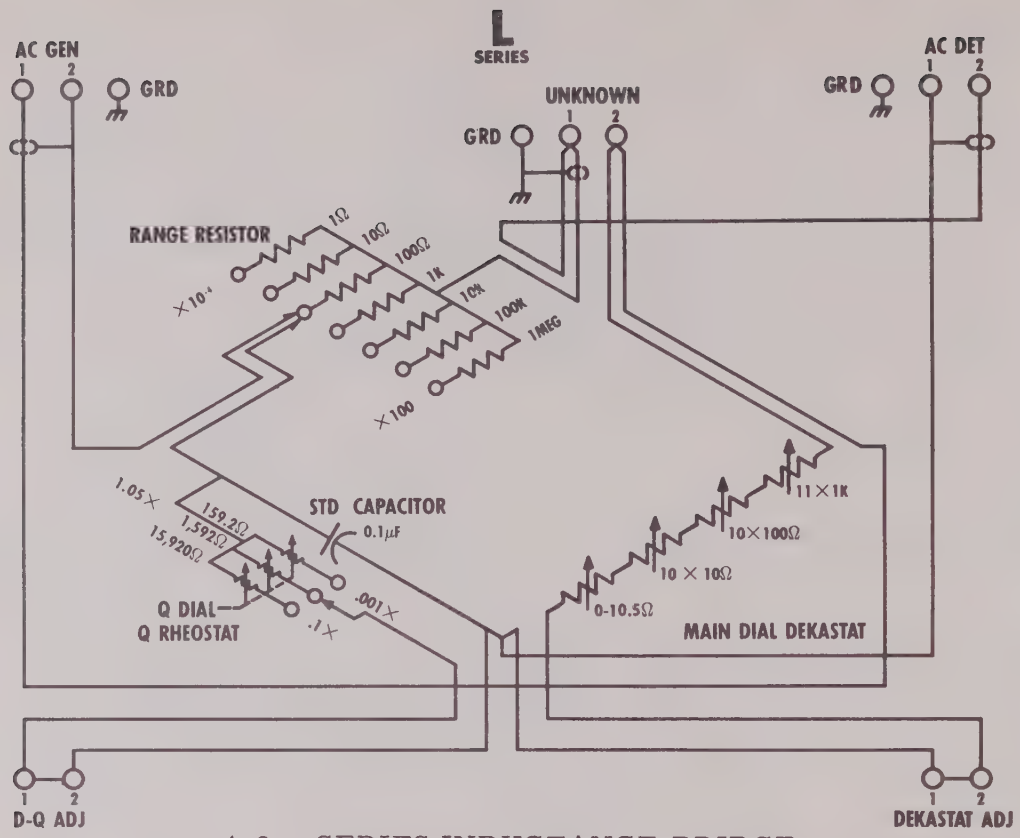
C_2 = Capacitance from unshielded conductor to ground



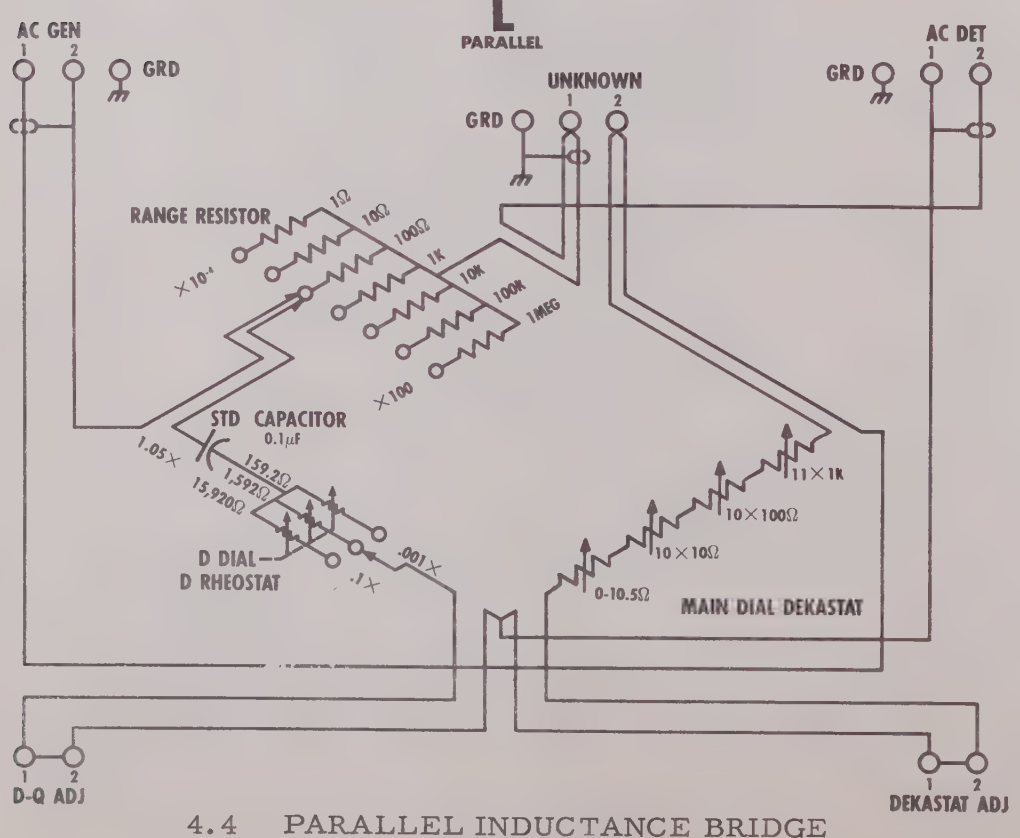
4.1 RESISTANCE BRIDGE



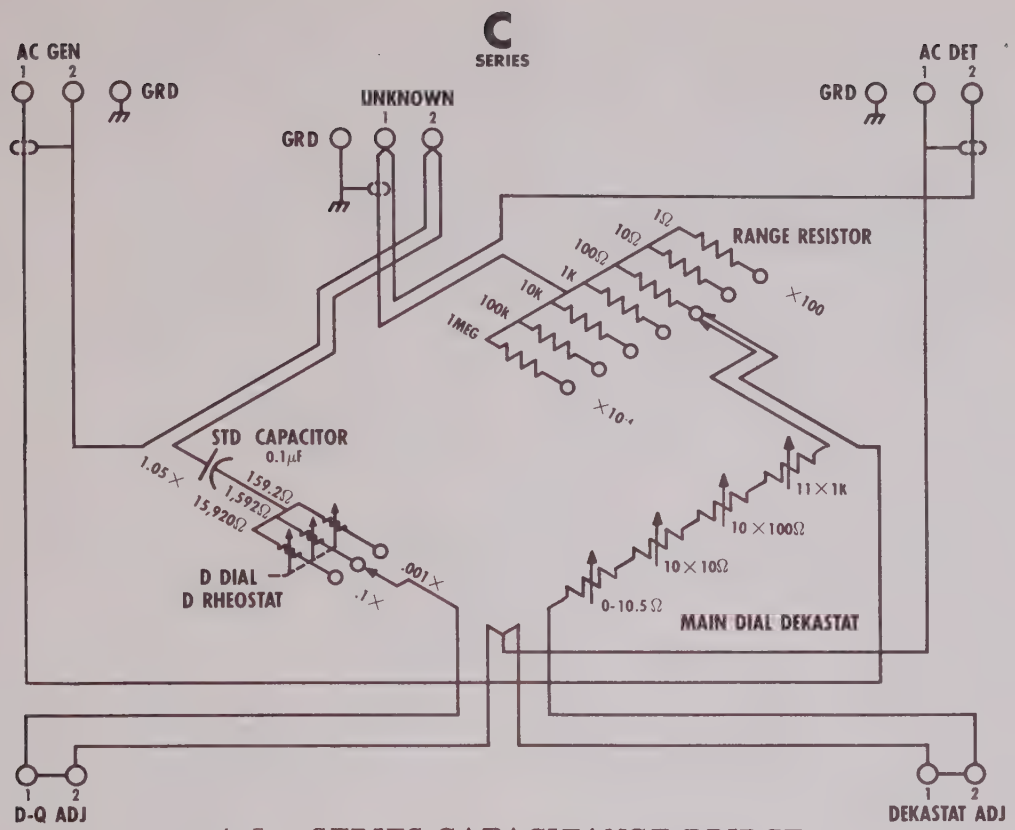
4.2 CONDUCTANCE BRIDGE



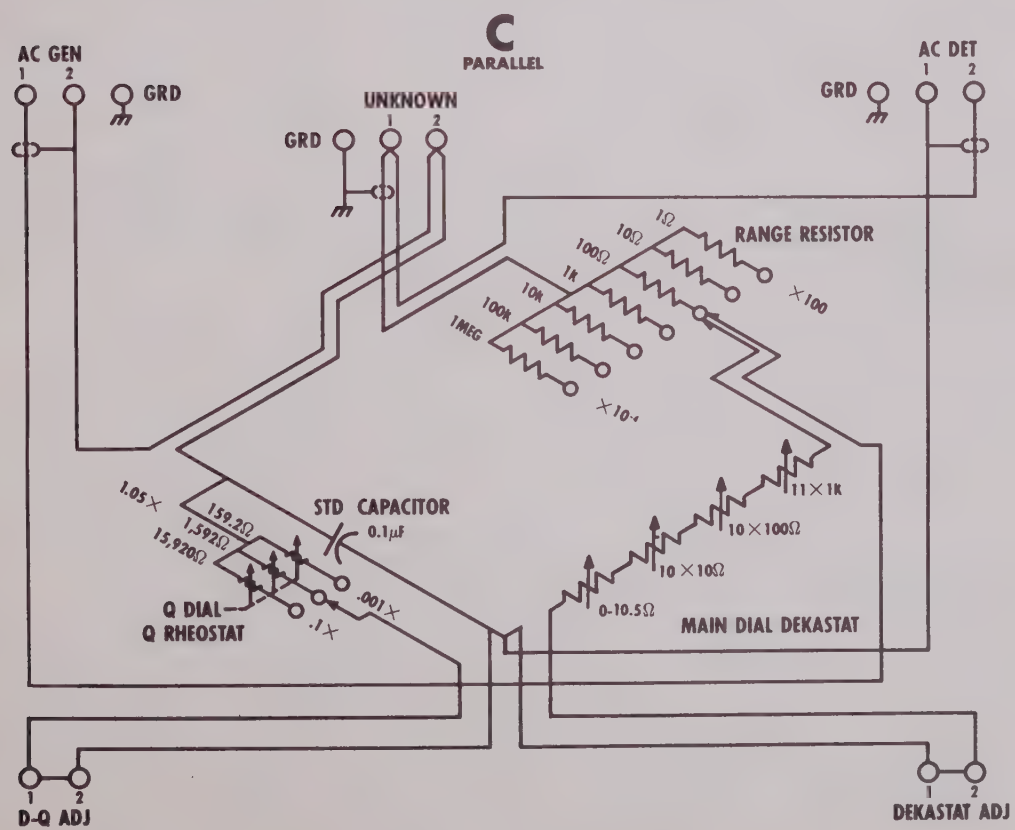
4.3 SERIES INDUCTANCE BRIDGE



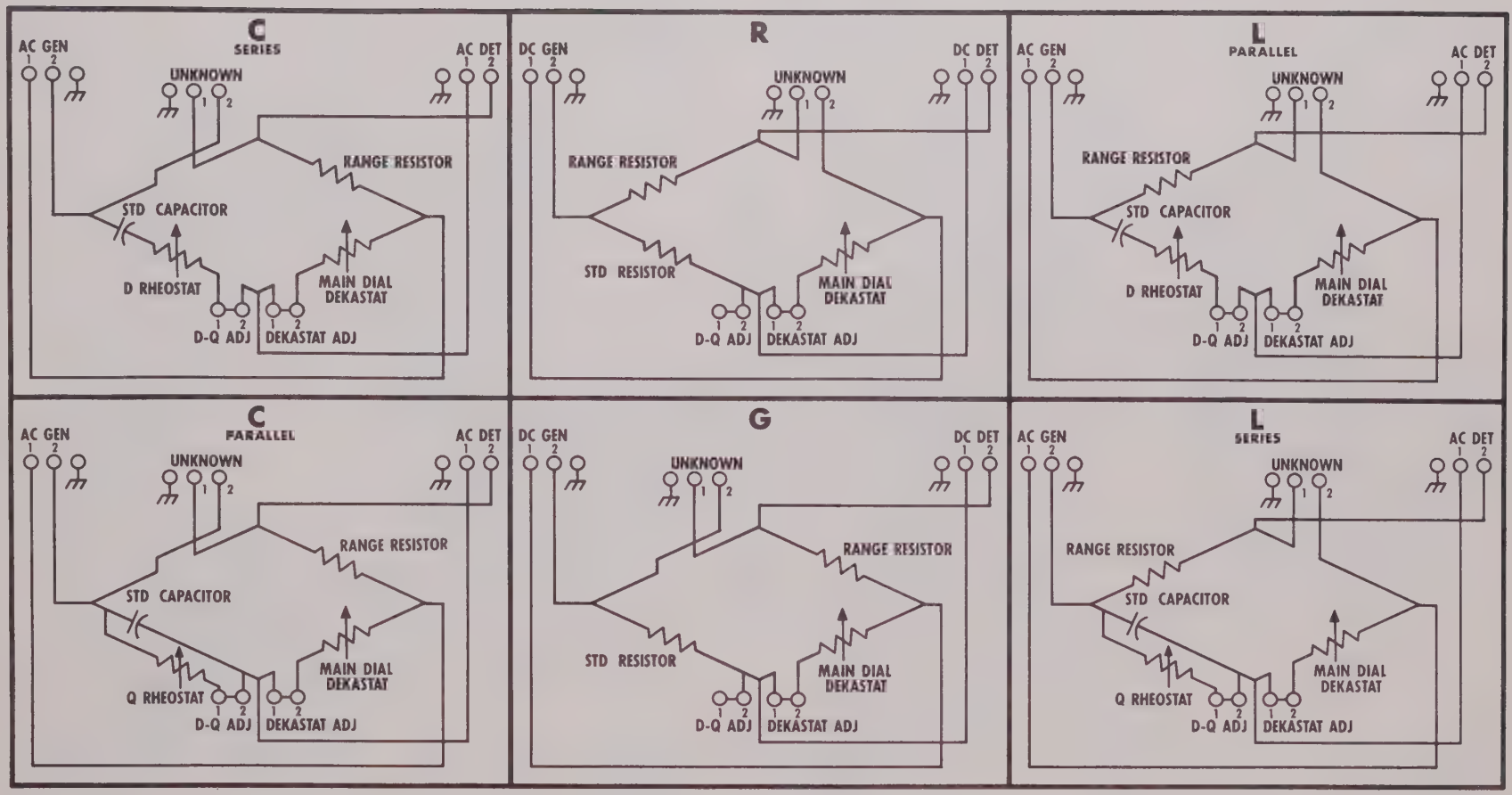
4.4 PARALLEL INDUCTANCE BRIDGE



4.5 SERIES CAPACITANCE BRIDGE



4.6 PARALLEL CAPACITANCE BRIDGE



4.7 BASIC CIRCUITS

5. BRIDGE ELEMENT VOLTAGE AND CURRENT LIMITS

RANGE RESISTORS

Safe Power limited to 1/2 watt per resistor

Resistance in Ohms	Max Voltage in Volts	Max Current in Milliamperes
1	0.71	710.00
10	2.30	230.00
100	7.10	71.00
1,000	23.00	23.00
10,000	71.00	7.10
100,000	230.00	2.30
1,000,000	250.00	0.25

D-Q RHEOSTATS

Safe power limited to 7 watts into total resistance

Resistance in Kilohms	Maximum Resistance in Ohms	Max Voltage in Volts	Max Current in Milliamperes
D-Q reading x 0.01592	166	35	210
D-Q reading x 0.1592	1,670	110	68
D-Q reading x 1.5920	16,750	350	21

STANDARD RESISTOR

Safe power limited to 1/2 watt

Resistance in Ohms	Max Voltage in Volts	Max Current in Milliamperes
10,000	71	7.1

MAIN DIAL RHEOSTAT

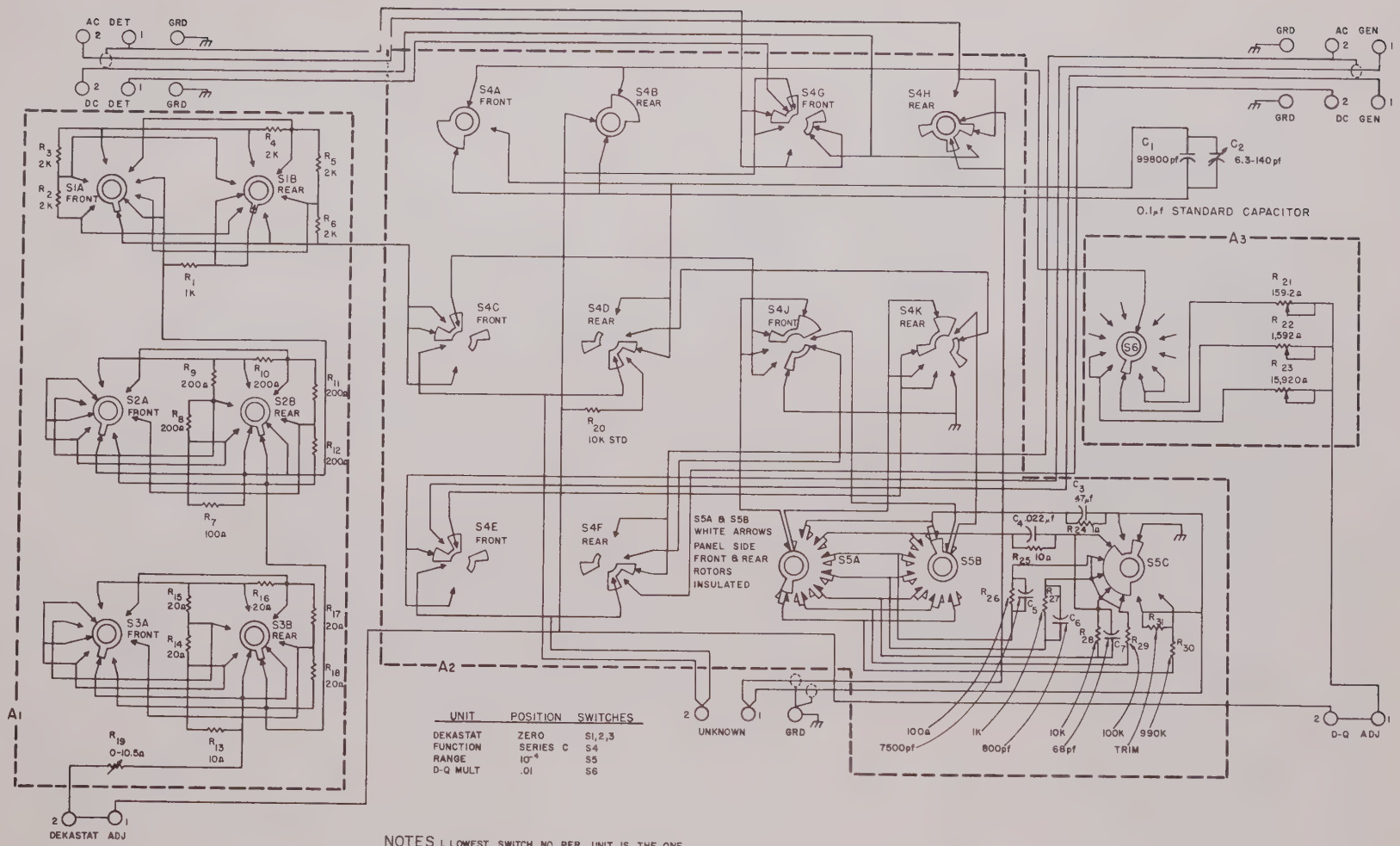
Safe power limited to 1/2 watt per step

Decade	Resistance in Ohms	Max Voltage in Volts per Step	Max Current in Milliamperes
First	1000Ω steps	23	23
Second	100Ω steps	7.1	71
Third	10Ω steps	2.3	230
Rheostat	0 - 10.5Ω	2.3 at max	230

6. CONVENIENT AUDIO FREQUENCY UNITS

For measurement and calculation in the audio frequency range the conventional electrical units are often inconvenient. A consistent set of units can be chosen so that the numerical values commonly encountered will be more practical while at the same time the equations used in calculations will not require any troublesome conversion constants. If either set of units listed below is followed consistently, the equations used for calculations will be unaltered. For example, E = IR holds true equally well with E in volts, I in amperes, and R in ohms; or with E in volts, I in milliamperes and R in kilohms. The 291 dials read directly in these "convenient" units.

Function	Conventional Units	Convenient Audio Frequency Units
ω	radian/sec = $2\pi f_{cps}$	kiloradian/sec = $2\pi f_{kc}$
f	cps	kc
t	second	millisecond
C	farad	microfarad
Z, R and X	ohm	kilohm
L	henry	henry
I	ampere	milliamp
E	volt	volt
P	watt	milliwatt
Q and D	per unit ratio	per unit ratio



NOTES 1. LOWEST SWITCH NO. PER UNIT IS THE ONE NEAREST THE PANEL
2. SWITCHES ARE VIEWED FROM THE BACK OF THE PANEL

MODEL 290A IMPEDANCE BRIDGE WIRING DIAGRAM

7. PARTS LIST

The following parts list is in alpha-numerical order of the circuit reference designator. Miscellaneous parts are included at the end of the list. Manufacturer of the part is given in a code number according to the Federal Supply Code for Manufacturers; see list of manufacturers below. Parts recommended as spares to sustain operation in isolated locations are indicated in the recommended spare parts column.

Parts manufactured by Electro Scientific Industries must be ordered from the factory. When ordering parts from the factory include the following information:

Model and serial number of the instrument
Electro Scientific Industries part number
Circuit reference designator
Description of part

CODE LIST OF MANUFACTURERS

11837	ELECTRO SCIENTIFIC INDUSTRIES Portland, Oregon
56289	SPRAGUE ELECTRIC CO. North Adams, Massachusetts
65092	WESTON INSTRUMENTS DIVISION OF DAYSTROM, INC. Newark, New Jersey
80583	HAMMARLUND CO., INC. New York, New York
84171	ARCO ELECTRONICS INC. Great Neck, New York

Ckt Ref	Description	Mfr	ESI Part No.	Qty Used	Recm SP
A_1	Ass'y, DEKASTAT	11837	3215	1	1
A_2	Ass'y, Multiplier Function	11837	3298	1	1

Ckt Ref	Description	Mfr	ESI Part No.	Qty Used	Recm SP
A_3	Ass'y, DQ Rheostat	11837	3211	1	1
C_1	Capacitor, Std 0.1μf	11837		1	1
C_2	Capacitor, variable, 6.3-140 pf Mfr PN APC-140-C	80583		1	
C_3	Capacitor, fixed, .47μf ±10%, Subminiature Metal Clad Mfr PN 178P479153, Part of Ass'y A_2	56289		1	
C_4	Capacitor, fixed, .022μf ±10%, Black Beauty Mfr PN 109P22342, Part of Ass'y A_2	56289		1	
C_5	Capacitor, fixed, 7500pf ±1%, mica, Mfr PN CM35E752F, Part of Ass'y A_2	84171		1	
C_6	Capacitor, fixed, 800pf ±5%, mica, Mfr PN CM20D8015, Part of Ass'y A_2	84171		1	
C_7	Capacitor, fixed, 68pf ±5%, mica, Mfr PN CM15E680J, Part of Ass'y A_2	84171		1	
R_1	Resistor, fixed, precision, 1k, Part of Ass'y A_1	11837	*	1	*
$R_{2,3,4,5,6}$	Resistor, fixed, precision, 2k, Part of Ass'y A_1	11837	*	5	*

* Replace entire ass'y

Ckt Ref	Description	Mfr	ESI Part No.	Qty Used	Recm SP
R_7	Resistor, fixed, precision, 100Ω, Part of Ass'y A_1	11837	*	1	*
$R_{8,9,10,11,12}$	Resistor, fixed, precision, 200Ω, Part of Ass'y A_1	11837	*	5	*
R_{13}	Resistor, fixed, precision, 10Ω, Part of Ass'y A_1	11837	*	1	*
$R_{14,15,16,17,18}$	Resistor, fixed, precision, 20Ω, Part of Ass'y A_1	11837	*	5	*
R_{19}	Resistor, variable, 10.5Ω, Part of Ass'y A_1	11837	*	1	*
R_{20}	Resistor, fixed, precision, 10k, Part of Ass'y A_2	11837	*	1	*
R_{21}	Resistor, variable, 159.2Ω, Part of Ass'y A_3	11837	*	1	*
R_{22}	Resistor, variable, 1592Ω, Part of Ass'y A_3	11837	*	1	*
R_{23}	Resistor, variable, 1592Ω, Part of Ass'y A_3	11837	*	1	*
R_{24}	Resistor, fixed, precision, 1Ω, Part of Ass'y A_2	11837	*	1	*
R_{25}	Resistor, fixed, precision, 10Ω, Part of Ass'y A_2	11837	*	1	*
R_{26}	Resistor, fixed, precision, 100Ω, Part of Ass'y A_2	11837	*	1	*

* Replace entire Ass'y

Ckt Ref	Description	Mfr	ESI Part No.	Qty Used	Recm SP
R_{27}	Resistor, fixed, precision, 1k, Part of Ass'y A_2	11837	*	1	*
R_{28}	Resistor, fixed, precision, 10k, Part of Ass'y A_2	11837	*	1	*
R_{29}	Resistor, fixed, precision, 100k, Part of Ass'y A_2	11837	*	1	*
R_{30}	Resistor, fixed, vamistor, 990k, Mfr PN 9852, Part of Ass'y A_2	65092		1	*
R_{31}	Resistor, fixed, sel. to adj R_{30}, Part of Ass'y A_2			1	*
$S_{1,2,3}$	Switch, Part of Ass'y A_1	11837	*	3	*
S_4	Switch, Part of Ass'y A_2	11837	*	1	*
S_5	Switch, Part of Ass'y A_2	11837	*	1	*
S_6	Switch, Part of Ass'y A_3	11837	*	1	*
	MISCELLANEOUS				
	Dial, DQ	11837	2780	1	
	Dial, Function	11837	3242	1	
	Dial, Main dial 1st	11837	4275	1	
	Dial, Main dial 2nd	11837	3332	1	
	Dial, Main dial 3rd	11837	3333	1	
	Dial, DQ mult	11837	3346	1	

* Replace entire Ass'y

Ckt Ref	Description	Mfr	ESI Part No.	Qty Used	Recm SP
	Dial, Main dial rheostat	11837	3344	1	
	Dial, Range	11837	3243	1	
	Knob	11837	1255	1	
	Cap, Binding Post Ins.	11837	1170	14	4
	Cap, Binding Post Metal	11837	1172	5	2
	Binding Post	11837	1393	19	
	Mask	11837	3375	1	
	Swing lug	11837	3247	2	
	Insulator, Binding Post,	11837	8823	8	
	Shield, Cover	11837	3331	1	
	Shield, Binding Post	11837	3295	1	
	Cover, Dust	11837	3347	1	

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Instrument Description: Model No. _____ Serial No. _____
(Please Print)

Name _____ Title _____

Department _____ Mail Stop _____

Company _____

Address _____

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Any comments or corrections? _____

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EB7 **Measuring Three-Terminal Capacitors,** *March 1962*

EB10 **Effects of Output Loading on Resistive Voltage Dividers,** *October 1966*

EB11 **To Use an External Q Rheostat for Inductance Measurements with the ESI Model 250 Bridge,** *May 1962*

EB15 **Low Input Resistance Voltage Dividers,** *March 1960*

EB20 **Calibration of a Decade Transformer Having One PPM Linearity,** *N. E. Morrison, April 1960*

EB23 **A New Approach to Bridge Sensitivity,** *Jack Riley, November 1962*

EB24 **Calibration of a Kelvin Varley Voltage Divider,** *Merle L. Morgan and Jack Riley, August 1960*

EB26 **International System of Units,** *August 1964*

EB29 **DC and Low Frequency AC Ratio Measurements,** *Dr. Merle L. Morgan, September 1962*

EB31 **Transformer Bridge Theory and Practice,** *Jack C. Riley, January 1964*

EB35 **An Improved Technique for Establishing Resistance Ratios,** *R. M. Pailthorp and J. C. Riley, November 1962*

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EB43 **Metrology Seminar WESCON 1964,** *September 1964*

EB44 **DC Measurements Using Ratio Techniques,** *Jack C. Riley, September 1965*

TA2 **A Ratio Transformer Bridge for Standardization of Inductors and Capacitors,** *D. L. Hillhouse and H. W. Kline, August 1960*

TA6 **The Accuracy of Series and Parallel Connections of Four-Terminal Resistors,** *Jack C. Riley, April 1965*

TA7 **Design of a Contemporary Direct Reading Double Ratio Set and Auxiliary Lead Compensator,** *Marion Roberts, April 1965*

TA8 **AC Measurements Using Ratio Techniques,** *Jack C. Riley, May 1965*

TA9 **Strength for the Weak Spot in DC Potentiometry,** *George D. Vincent and M. L. Roberts, October 1965*

TA10 **Resonant Capacitance-Inductance Transfer Using the Ratio Transformer,** *D. L. Hillhouse, July 1966*

TA11 **An International Comparison of Inductive Voltage Divider Calibrations at 400 and 1000 Hz,** *W. C. Sze, A. F. Dunn, and T. L. Zapf, January 1967*

TA12 **On Resistances with Current and Potential Terminals,** *G. F. C. Searle, January 1967*

TA13 **A 1-100Ω Build-Up Resistor for the Calibration of Standard Resistors,** *B. V. Hamon, January 1967*

TA14 **The Advantages of a Ten Kilohm Transportable Resistance Standard,** *Robert M. Pailthorp, September 1967*

TA15 **A Programmable System for Instrument Calibration,** *Richard A. Schomburg, October 1967*

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